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SOVIET INSTRUMENTATION AND CONTROL TRANSLATION SERIES

Measurement Techniques

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Measurement Techniques

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NEW STAGE IN STATE TESTING OF MEASURING INSTRUMENTS

N. M. Karelin and N. I. Tyurin

Translated from Izmeritel'naya Tekhnika, No. 9,
pp. 1-5, September, 1961

Regulations 2-59 for state testing of measures and measuring instruments are intended for accelerating the rate of technical development and speeding up the introduction of new equipment in this branch of our national economy. The regulations came into force on April 1, 1960 [1] and were drafted by the Committee of Standards, Measures and Measuring Instruments in conformity with the tasks outlined by the 21st Congress of the C.P.S.U. (Communist Party of the Soviet Union) and the June (1959) plenary session of the CPSU central committee.

The experience accumulated since then makes it possible to draw certain conclusions and outline various measures for raising the efficiency of testing.

Testing of experimental models. The importance of testing newly developed models before putting them into mass production was noted by the June (1959) plenary session of the CPSU central committee and stressed in a number of subsequent directives of the higher administrative organizations. Complying with these instructions, the system of state testing was reorganized, and by 1960 the number of experimental models tested by the VNIIK (All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments) amounted to 75% of all their testing, as compared with 26% in 1956.

Our experience has shown that the most rapid assimilation of new measuring equipment occurs when the development is carried out by the manufacturing plant. Experimental models are presented then, as a rule, in a form suitable for mass production. According to the new rules the Committee approves the instruments for mass production without any further testing of mass produced models, providing the original tests of experimental models prove satisfactory. Among the instruments which passed their testing in that manner we can note: the optical height gauge IZV-2, which is superior both to model IZV-1 and the foreign-made Abbé height gauge with respect to its accuracy and operating properties; the volt-ampere-wattmeter D-552, which is an improvement on model D-501, etc.

However, in the majority of cases tests revealed the need for further development of the instrument or its additional testing. If it was only found necessary to improve a fundamentally sound design, permission was granted to manufacture an experimental batch of instruments, thus making it possible to test them under operating conditions. Such instruments include, for instance, the group of differential manometers with induction transducers (DMKK, DMKV, and DMI) developed by the Khar'kov KIP Plant and used together with indicating instruments VF. These manometers have a new and efficient design, but they are sensitive to the effect of external magnetic fields.

In several instances the opinions expressed after testing were of such a nature that it was impossible to approve the manufacture even of an experimental batch. Out of all the instruments tested in 1960 by the VNIIK 36% were not passed for mass production. The models were returned for testing and redesigning, and only after a second and sometimes even a third test, were they passed for production. The reasons for rejection usually consisted of defects in the design, failure to meet the GOST (All-Union State Standard) technical or operational requirements, and unsatisfactory quality in the production of the experimental models. In certain cases satisfactory instruments were rejected owing to their bad technical descriptions and unsatisfactory test methods adopted at the factory, which did not provide reproducibility of the characteristics and parameters of these instruments.

In order to provide a more thorough and exhaustive evaluation of the experimental models of the most important and complex measuring instruments, they are tested by interdepartmental commissions consisting, in addition to representatives of the Committee's institutes, also of representatives of the organization which developed the instrument, the manufacturing plant, and also representatives of the interested organizations.

The test results of the most important instruments are discussed at meetings regularly convened by the VNIIK with the participation of representatives of the State Planning Committees of the USSR and the RSFSR (Russian Socialist Federated Soviet Republic), State Committees of the USSR Council of Ministers, Councils of National Economy, ministries, experts from scientific research organizations, and the most important plants. The commissions and conferences help the Institute to provide a fuller evaluation of the tested instruments and find their operational properties over a wider range of application.

The more exacting requirements specified by various branches of our industry with respect to measuring instruments make the participation of interested specialized organizations in state testing desirable not only to the extent of taking part in interdepartmental commissions, but also by making specialized industrial institutes carry out the testing according to a program agreed upon with the VNIIK. Thus, the majority of the tests of grain-moisture meters are carried out by All-Union Scientific Research Institute of Grain. Instruments for measuring the geometrical parameters of cutting tools are tested by the All-Union Scientific Research Institute of Tools. Measuring instruments involved in the automation of measuring dimensions in engineering will be tested in the same manner by the Bureau of Interchangeability.

Assimilating new measuring equipment. The rapidly rising requirements of various branches of our national economy, new measuring methods and instruments, the use of measuring mechanisms based on new principles of operation, and the application of modern technology to instrument-making, result in the production of improved measuring instruments every year. The production of obsolete instruments is, naturally, discontinued as soon as the mass production of new instruments is assimilated. However, there have been instances when certain plants organized the mass production of instruments on the basis of models from another plant which was already preparing to manufacture an improved version of the instrument. In this connection the State Register of measures and measuring instruments passed for production and use in the USSR acquires particular importance. The register includes instruments whose development both with respect to their design and construction has been completed. The opposite action, i.e. the exclusion of instruments from the register, is also of considerable importance; it means that the production of this instrument is not only discontinued at a given plant, but it is forbidden to manufacture it in any plant. Over 70 instruments were excluded from the State Register in 1960.

In order to obtain a more complete picture of the new measuring equipment assimilation, it is necessary to add to new instruments replacing obsolete versions also those providing measurements of a type or in a range not previously covered. As an example of the latter type of instruments it is possible to quote reference resistors R70 of 1 and 10 meg intended for use at dc and ac, up to 1000 cps; resistance boxes MSSh-70 and MSSh-72 (up to 1000 meg). These instruments constitute a new and major achievement of the Soviet instrument-making industry, considerably in advance of foreign technology. The new and original instruments also include 10 v portable electrostatic voltmeters S-70 for frequencies up to 5 Mc, and other instruments.

Certain defects in the work of instrument-making plants. The USSR State Planning Committee and the State Committee on Automation and Engineering of the USSR Council of Ministers approved on November 20, 1959, in accordance with the decisions of the June (1959) plenary session of the CPSU central committee, the "model regulation on the method of developing, manufacturing and testing of experimental models of new machines, equipment, instruments and other engineering products, and on preparing them for mass production." This resolution states clearly and categorically that manufacturing plants should organize all the development, testing and preparation for mass production of new articles, obtaining if necessary the cooperation of development and design, and scientific-research, organizations.

The experience in state testing of measures and measuring instruments has fully confirmed the efficiency of organizing the development in instrument-making on this basis, which leads to the rapid assimilation of the new equipment. Unfortunately, not only this but also other regulations are fulfilled by the instrument-making plants in an unsatisfactory manner.

The existing special design offices and scientific-research institutes often develop new measuring instruments independently of the prospective manufacturing plant and without considering the latter's technological possibilities. The development of such instruments is followed by a struggle between the design organization, which strives to place this instrument in mass production, and the manufacturing plant, which refuses to accept the design, considering it unfinished and unsuitable for production, etc.

The same Model Regulation clearly notes that the basic technical document for developing new models should be the specifications agreed upon in a definite manner. However, very few instruments are submitted for testing ac-

companied by a technical specification, and even when such a specification does exist, it has not been discussed with a wide circle of interested customers, let alone agreed upon with them. At the above-mentioned technical conferences representatives of industry often pointed out the discrepancy between the selected instrument characteristics and the requirements of customers. As an example we may cite the large number of different designs for avo instruments [2] whose technical requirements and operating conditions have been approved by the Sovnarkhozes (councils of national economy) without previous agreement with the customers.

Often a development is started on the initiative of a plant or a design bureau without a sufficient study of the requirements for the instrument or of its technical and economic characteristics.

In approving technical specifications the organizations concerned do not fulfill the conditions laid down by the USSR State Planning Committee on March 17, 1960, in agreement with the Committee of Standards, Measures and Measuring Instruments, in the "Instruction on the method of compiling and approving technical specifications for industrial products." This instruction requires that technical specifications should be agreed upon by a wide range of organizations: consumers, manufacturers and designers of similar products, leading (area) institutes, etc. In addition to the designers, a part of the blame for failing to fulfill this instruction also falls on some of the leading industrial institutes which formally register specifications instead of analyzing and criticizing them.

Another very important defect in the specifications consists of their lack in determining the required methods of testing according to modern requirements. Often designers develop instruments with various outstanding properties without knowing how these instruments can be tested, or else applying obviously unsatisfactory methods for this purpose. It is inadmissible for designers to submit a new instrument for testing, leaving it for the testers to solve the problem whether the instrument possesses the specified accuracy or not. The development of a method for testing an instrument for any given characteristic, however, often takes longer than the development of the instrument itself. For instance, refractometer readings of refraction and mean dispersion were tested with uncertified prisms. Thus it became necessary, side by side with developing the refractometer, to develop at the VNIIK methods and means for checking refractometers and certifying prisms, a task which required about two years to fulfill. As a result of this work both the Institute and the plant were able to test the refractometer in a satisfactory manner. However, it is not always possible to attain such parallel development. Thus, when compensating differential manometers DMPK-100 for pressures of 40 to 630 mm Hg with a measuring error not exceeding ± 0,5% were submitted for testing without adequate preparations, it was necessary to set up and adjust an equipment for testing these instruments at full static pressure, which delayed the assimilation of these instruments in industry.

It is not only the lack of methods, but also the lack at the plants of testing equipment of existing types which delays the assimilation of new instruments. Thus, in ten cases of state testing of electrical measuring instruments the VNIIK was able to extend their frequency application range as compared with that specified by the designers. In this connection a well-known testing method was used, on the basis of which the Institute as long ago as 1959 developed an equipment for determining the effect of high-frequency magnetic fields on the instrument readings.

The four-decade mutual inductance box R538 developed by the "Tochélektropribor" Plant is considerably superior to foreign-made boxes, but despite satisfactory test results this instrument was not approved for production since the plant lacked measuring equipment for the accurate determination of its parameters. Under the above conditions the plant was unable to reproduce the characteristics of the instrument model. Only when the plant constructed the required equipment on the basis of the research work carried out by the VNIIK, was permission granted for the manufactured of the high-precision boxes R538. The production of this instrument was delayed for more than six months owing to the lack of measuring instruments at the plant.

In 1960 the production of many instruments was transferred to other plants, which was a completely justifiable measure, since it released the best-equipped plants for the production of new, more complex instruments. However, this transfer was accompanied by considerable errors and even infringements of the existing specifications. The designers often submit to the plants for mass production instruments which have not been completely developed. In several instances the experimental models of instruments submitted for state testing were not considered ready for mass production; in the most favorable cases only the production of an experimental batch was allowed, which normally indicates the need for further development work. There were instances when instruments were passed for mass production even without having been submitted to state testing. The originating organizations do not always inform the production plants of the defects which have been discovered in factory or field testing. As a result of this the production of instruments is either delayed for a considerable time, or under some pretext or another instruments are produced

whose design and construction are not completely developed. The development of the construction and the first model has to be completed by the manufacturing plant, which lacks experience of working with the given instrument; moreover, this has to be done when the tooling is completed and the manufacture started of an instrument which is known to be incompletely developed.

Regulations 2-59 require that in transferring the production of instruments from one plant to another, the latter plant must receive permission for the production of each type of instrument from the Committee of Standards, Measures and Measuring Instruments (and not from one of its agencies). This requirement aims at stopping the production of obsolete or unsatisfactory designs. However, this rule is not always fulfilled. It is surprising that the Sovnarkhozes and production plants do not utilize this requirement, which protects them from considerable unproductive expenditure and dislocation in the measuring-instrument production plans. Our GKLs (State Inspection Laboratories) exercise insufficient control over the fulfillment of this requirement.

The Model Instruction states that the plant which produces a commodity according to specifications of another plant (design originator) must have the agreement of that plant for any modifications in the design of the commodity. The originating plant, on the other hand, must inform all the manufacturing plants working according to its specifications of any changes in the design of the commodity. This instruction is disregarded in many instances in the instrument-making industry, thus often leading to disastrous results. For instance, the "Tochélektropribor" Plant transferred the production of portable instrument transformers to the Uman' Plant. The latter plant, lacking sufficiently wide experience in their manufacture, carried out various erroneous "rationalizations" without the consent of the "Tochélektropribor" Plant. As a result of this the operational properties of the transformers deteriorated considerably.

Tasks of the Institutes and the GKLs of the Committee of Standards, Measures and Measuring Instruments. Measurement technology and instrument-making are developing on a wide front in various directions, thus presenting special tasks for the scientific research institutes of the Committee of Standards, Measures and Measuring Instruments.

In carrying out state testing of new measuring instruments the Committee's institutes should, in addition to determining the accuracy and operational reliability of instruments, also evaluate the testing methods for these instruments suggested by their designers, in order to ascertain whether these methods are suitable for determining the parameters and characteristics of the instruments. The lack of specified satisfactory test methods should be considered as an unfinished development of the instrument.

Both the technical and organizational aspects of testing methods are of considerable importance.

As an example of a general technical aspect of testing methods we can note the testing of instruments which include standardized components or units, produced by specialized plants with specified deviations from their nominal characteristics. Tests of instruments with essential components whose parameters were varied within specified limits have shown that designers often fail to take into consideration the possible dispersion of these parameters. In certain cases the variation of the detail's parameters within tolerances led to the instrument error rising up to 50% instead of the normal 3-5%. A method for testing instruments with standardized details is being studied by the Institute.

The supervision by the VNIIK over the testing methods practiced by the Committee's agencies as well as by organizations of other departments consists in coordinating programs, analyzing reports, providing advice (including visits to locations), supplying information, compiling card indexes, etc.

VNIIK's supervision of the working methods is most adequately expressed in its "Temporary Instructions on the methods of state testing of measuring instruments according to the Committee's Regulations 2-59."

According to Regulations 2-59 the GKLs are now testing periodically the current production of instrument-making plants instead of carrying out the abolished check-testing. Moreover, the GKLs are now obliged to establish at each testing whether the manufactured instruments correspond to the modern level of measurement technology and meet the requirements of our national economy, and to evaluate the material collected by the Committee's agencies on the operational properties of these instruments.

In addition to these periodic tests and the planned or special check-testing, the GKLs must carry out state testing of new instruments prepared for mass production, and in some instances they must also test the experimental

models. The GKLs must test, for instance, experimental models whose design has been changed by the plants in order to satisfy criticisms made by the institute which tested the first experimental model. The reports of such tests made by the GKLs are examined by the institute, which makes the required recommendation to the Committee.

The undoubted rise in the technical level of the GKLs and the stricter requirements specified for testing should be noted. However, some of the GKLs carry out state testing of current production of the instrument-making plants on the level of ordinary extensive testing without analyzing the results or evaluating the adequacy of the design in their reports.

Immediate tasks in state testing of measuring instruments. The most serious attention should be paid to ensuring the operational reliability of instruments. The technical requirements of the instruments do not always specify their operational characteristics, thus making it impossible to evaluate in testing the extent to which their operational reliability has been satisfied. Checking the reliability of instruments by observing the behavior of an experimental batch under operational conditions requires a considerable time and delays the application of instruments, sometimes for several years. Moreover, tests under normal operating conditions do not provide a rapid evaluation and elimination of defects, since they do not involve voluntary changes in operating conditions over wide ranges. In order to reduce to the minimum the time required for developing the first model, by ensuring reliable functioning of instruments under varying operating conditions, it is necessary to develop new methods and various types of equipment for testing the effects produced on the instruments by climatic conditions, mechanical strength and other factors which influence the reliability of a design and long-term preservation of the instrument's metrological characteristics.

Methods for the accelerated evaluation of an instrument's operating characteristics under laboratory conditions should be developed. One such method consists of the use of extreme operating conditions which should be strictly defined. This is a major scientific problem whose solution should be based, among other things, on the similarity theory, etc.

In this respect a very large amount of work still lies ahead.

Decisive measures should be taken to ensure precise and strict adherence to government instructions and requirements specified by superior organizations in testing and manufacturing measuring instruments.

The specialization of measuring instruments makes it necessary to seek the participation in testing of those organizations for whose use the instruments are intended. The instruments whose testing is allocated to the Committee's institutes and those to be tested by interdepartmential commissions should be specified.

The responsibility for testing some of the instruments should be allocated to the State Committees of the USSR Council of Ministers on Radioelectronics, Automation and Engineering.

In the near future such a testing routine should be expressed in a clear organizational form.

Such an organization of state testing would leave the Committee's Institutes, and especially the VNIIK, free to exercise general supervision of the testing methods and coordinate the testing.

State testing of measures and measuring instruments should become the concern of the state in the widest sense of this word. All Soviet specialists should take part in carrying them out. For a thorough testing of instruments the equipment of all scientific-research, educational and other organizations should be available.

The implementation of these measures as well as the elimination of the defects mentioned in this article will provide further improvement of our instrument-making industry and thus help to establish and develop the material and technical basis for communism envisaged by the Draft Program of the CPSU to be discussed by the 22nd Congress of the CPSU.

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INVESTIGATING THE EFFICIENCY OF PLANE-PARALLEL LAPPING OF GAUGES

A. M. Vedmidskii

Translated from Izmeritel'naya Tekhnika, No. 9, pp. 5-7, September, 1961

Plane-parallel lapping, which constitutes the finishing operation in the manufacture and repair of many gauges and calipers, has not been sufficiently studied up till now. We provide below the method and the results of our investigations of lapping, which we hope can be used as the scientific basis in determining the optimum conditions for mechanical lapping which would provide the required accuracy.

We investigated the lapping of 22 block gauges with an operational dimension of 4.5 mm by means of a disc lapping machine.

After the first lapping the gauges were measured and oxidized in order to provide a picture of the removal of the allowances off the gauges' operating faces. For the second lapping the gauges were placed in the holders of the device. The microabrasive powder consisted of electrocorundum M14.

The data thus obtained are shown in Table 1.

TABLE 1

Block gauge nos.	Time of lapping, sec	Deviation of mean dimension after first lapping, μ	Deviation of mean dimension after oxidation, μ	Deviation of mean dimension after 2nd lapping, μ	Amount of metal removed in lapping from both sides, μ	Mean value of metal removed from both sides in the 2nd lapping, μ			
						expt. $Z_{m.e}$	calc. $Z_{m.c}$	$\epsilon = Z_{m.c} - Z_{m.e}$	$\frac{Z_{m.e}}{t_i}$
9	15	+11.5	+13.0	+ 8.0	5.0	5.05	5.22	+0.17	0.34
22	15	+ 9.0	+10.5	+ 5.4	5.1				
19	30	+ 9.5	+11.0	+ 7.0	4.0	6.45	7.27	+0.82	0.21
14	30	+10.5	+12.0	+ 3.1	8.9				
21	40	+10.5	+12.0	+ 1.8	10.2	10.35	8.73	−1.62	0.26
1	40	+10.0	+11.5	+ 1.0	10.5				
3	50	+10.0	+11.5	0	11.5	10.75	10.27	−0.48	0.22
15	50	+10.5	+12.0	+ 2.0	10.0				
6	60	+10.5	+12.0	+ 0.6	11.4	11.90	11.93	+0.03	0.20
2	60	+ 9.5	+11.0	− 1.4	12.4				
18	70	+ 8.5	+10.0	− 1.3	11.3	13.10	13.74	+0.64	0.19
10	70	+10.0	+11.5	− 3.4	14.9				
16	80	+ 9.0	+10.5	− 3.6	14.1	13.70	15.40	+1.70	0.17
13	80	+ 8.0	+ 9.0	− 4.3	13.3				
17	90	+11.5	+13.0	− 5.2	18.2	14.60	17.21	+2.61	0.16
11	90	+ 9.0	+10.0	− 1.0	11.0				
4	100	+ 9.0	+10.0	− 7.5	17.5	20.65	19.14	−1.51	0.21
7	100	+11.5	+13.0	−10.8	23.8				
8	110	+11.5	+13.0	−12.0	25.0	23.05	21.16	−1.89	0.21
12	110	+11.0	+12.5	− 8.6	21.1				
20	120	+11.5	+13.0	− 8.4	21.4	23.20	23.34	+0.14	0.19
5	120	+11.5	+13.0	−12.0	25.0				

In order to find the characteristic relation between the amount of the removed metal and the lapping time of block gauges, $Z = f(t)$, we worked out the experimental data according to the least squares method, i.e. the minimum sum of the squares of the experimental points' deviation from a curve in the vertical direction (the minimum sum of the squares of ϵ).

In our case the number of experimental points was $n_e = 11$, and the empirical formula we used consisted of three terms:

$$Z = B_0 + B_1 t + B_2 t^2. \tag{1}$$

The solution of the above problem consists in determining the numerical values of B_0, B_1 and B_2.

By inserting in the above formula the consecutive values of Z and t we obtain the following 11 primary equations

$$\begin{aligned} &B_0 + 15B_1 + 225B_2 - 5.05 = \varepsilon_1, \\ &B_0 + 30B_1 + 900B_2 - 6.45 = \varepsilon_2, \\ &\quad\cdots\cdots\cdots\cdots \\ &B_0 + 120B_1 + 144000B_2 - 23.20 = \varepsilon_{11}. \end{aligned} \tag{2}$$

Having squared the left-hand sides of the equations and added them together we obtain the following expression by denoting $\sum_1^{11} \varepsilon^2$ by F:

$$\begin{aligned} &(B_0 + 15B_1 + 225B_2 - 5.05)^2 + (B_0 + 30B_1 + \\ &\quad + 900B_2 - 6.45)^2 + \ldots + \\ &+ (B_0 + 120B_1 + 144000B_2 - 23.20)^2 = F. \end{aligned} \tag{3}$$

Having obtained partial derivatives of the left-hand side of the equation with respect to B_0, B_1 and B_2 and equated them to zero, we obtain by means of transformations according to K. P. Yakovlev's method [1] normal equations whose solution provides the numerical values of coefficients B_0, B_1 and B_2.

If the coefficients of B_0 in all the primary equations are equal to unity, the coefficient of B_0 in the first normal equation will consist, according to the general scheme established by us, of the number of primary equations n; the coefficient of B_1 will consist of the sum of all the t, and the coefficient of B_2 of the sum of all the t^2.

TABLE 2

1st equation			2nd equation		3rd equation	
t	t^2	Z	t^3	tZ	t^4	t^2Z
15	225	5.05	3375	75.8	50625	1136.3
. . .	. . .	. . .	. . .	. . .	. . .	. . .
120	14400	23.20	1728000	2784.0	207360000	334080.0
$\Sigma t = 765$	$\Sigma t^2 = 64725$	$\Sigma Z = 152.8$	$\Sigma t^3 = 6078375$	$\Sigma tZ = 12646.3$	$\Sigma t^4 = 606980625$	$\Sigma t^2 Z = 1182831.3$

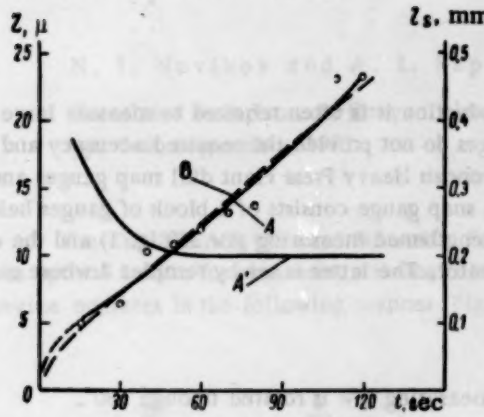
In the second and subsequent normal equations the coefficients of B consist as before of the sum of t, but each addend of these sums figures in the indices, in the second normal equation one unit higher than the corresponding index of B, and in the third equation two units higher. The free term of the first equation is equal to ΣZ, of the second to ΣtZ, and of the third to $\Sigma t^2 Z$.

Thus, for our conditions we obtain the following system of equations:

$$\begin{aligned} nB_0+\sum tB_1+\sum t^2B_2&=\sum Z,\\ \sum tB_0+\sum t^2B_1+\sum t^3B_2&=\sum tZ,\\ \sum t^2B_0+\sum t^3B_1+\sum t^4B_2&=\sum t^2Z. \end{aligned} \tag{4}$$

The number of addends in each expression of Σ amounts to 11.

The calculated numerical values of the sums are shown in Table 2.



On completion of the above operations we obtain the normal equations

$$\begin{aligned} 11B_0+765B_1+64725B_2&=152.8,\\ 765B_0+64725B_1+6078375B_2&=12646,\\ 64725B_0+6078375B_1+606980625B_2&=1182831. \end{aligned} \tag{5}$$

By solving them we obtain $B_0 = 3.34$, $B_1 = 0.119$, and $B_2 = 0.00039$.

Thus, the empirical formula which we found by the least squares method has the form

$$Z = 3.34 + 0.119t + 0.00039t^2, \tag{6}$$

where Z is the amount of metal removed in lapping both sides, μ; t is the lapping time (current), sec.

The plotting of the characteristic relation between the amount of the removed metal and the time in lapping block gauges, $Z = f(t)$ (see figure), indicates the existence of a regular relationship which approaches linearity. The divergence between the full line A plotted from (6) and the dotted line B plotted from Table 1 is extremely small.

The empirical formula calculated by us by means of the least squares method assuming a linear relationship (straight line B) has the following form:

$$Z = 1.86 + 0.1733t. \quad (7)$$

The mean amount of metal removed from both sides per unit of time from the beginning of lapping is equal to $Z_s = Z_{m.e}/t_l (\mu/\text{sec})$ and is characterized by a curve A' (see figure) plotted from (6).

If we assume (7) to be the initial equation, the mean amount of metal removed per unit time in plane-parallel mechanical lapping of block gauges will be determined as

$$Z_s = 0.1733 + \frac{1.86}{t}.$$

The above empirical formulas hold for $t > 15$ sec. It should be noted that at the beginning of lapping a more intensive removal of metal occurs, owing to considerable surface irregularities which remain from the previous machining, as well as owing to the existence of the oxide film on the lapping surface.

LITERATURE CITED

1. K. P. Yakovlev, Mathematical Treatment of Measurement Results [in Russian] (GITTL, Moscow, 1950), pp. 366-370.

EFFICIENT MEANS FOR MEASURING LARGE SIZES

A. M. Barskii and L. M. Shereshevskii

Translated from Izmeritel'naya Tekhnika, No. 9, pp. 7-8, September, 1961

In the industrial practice of individual or small-scale mass production it is often required to measure large sizes, of the order of 1500-3000 mm. Measurements by means of slide gauges do not provide the required accuracy and the manufacture of special linear snap gauges is not justified. At the Voronezh Heavy Press Plant dial snap gauges and home gauges are rapidly adapted for the purpose. The basis of such a snap gauge consists of a block of gauges held together by couplers. One side of the gauge block is connected to a lengthened measuring jaw 1 (Fig. 1) and the other end to a special measuring jaw 2, with a hole for fixing a lever indicator. The latter is set by templet 3, whose measuring base consists of the measuring jaw 2.

The length of the gauge block is $B = A - a$.

When the above device is used for internal measurements the measuring jaw is rotated through 180°.

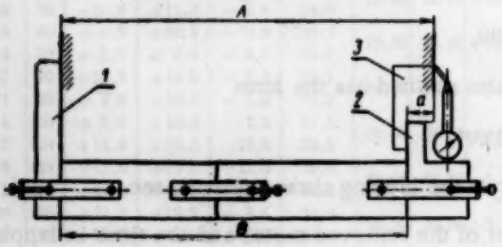


Fig. 1.

The application of this indicating device eliminates the error which arises in a normal setting of snap gauges against a reference measure, a gauge block or another reference device; it reduces the error in estimating the contact pressure; and it provides rapid measurements under production conditions.

In order to raise the accuracy of measuring large sizes slide gauges with incorporated indicating devices are also used. In such a slide gauge the sliding jaw is replaced by a special jaw with an $8A_{2a}$ hole which takes the stem of a dial type indicator.

The zero is adjusted in the following manner: the sliding frame is moved toward the stationary jaw until it touches the indicator. Next the zero calibrations of the gauge and vernier scales are made to coincide. A gap of some 5 mm will then be obtained between the jaws, due to the displacement of the vernier scale and its shortening when required. The indicator is fixed in position with a strain of 1 mm. The sliding frame is set to the measured size by the vernier scale and used as an indicating snap gauge with an absolute reading.

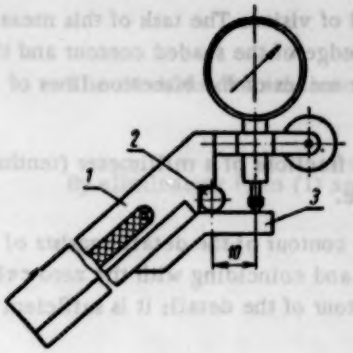


Fig. 2.

For checking angles with a large side at the apex (press guides, sliders, etc.) an indicating angle-measuring templet has been made (Fig. 2), whose use raises the efficiency of checking.

A gauge-type rule 1 with a bevel carries roller 2 and a dial-type indicator calibrated in 2 or 1 μ.

The base of the instrument consists of the distance between the axis of the bearing roller and that of the measuring rod, which is equal to 10 mm. If the smaller side of the measured angle is long enough it is possible to increase that base, thus raising the accuracy of measurement.

The angle gauge is set against a special templet 3 or angle-plates.

The indicator is set to zero with a strain of 1 mm. Next the angle gauge is transferred onto the component and the linear deviation of the angle is measured on the indicator. The deviation in angular units is obtained from appropriate tables.

The surfaces of the measured angle faces must be kept clean when using the angle gauge. If the measured surface has traces of machining a block gauge should be placed under the measuring rod of the indicator. In this case the roller should also rest against the gauge.

CONTACTLESS OPTICAL DEVICE FOR MEASURING DIAMETERS OF LARGE COMPONENTS

N. I. Novikov and A. I. Sapozhkov

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The TsNIITMASh (Central Scientific Research Institute of Technology and Machinery) has developed a contactless optical device for measuring external diameters of large details during their machining on turning lathes. This device operates in the following manner (Fig. 1).

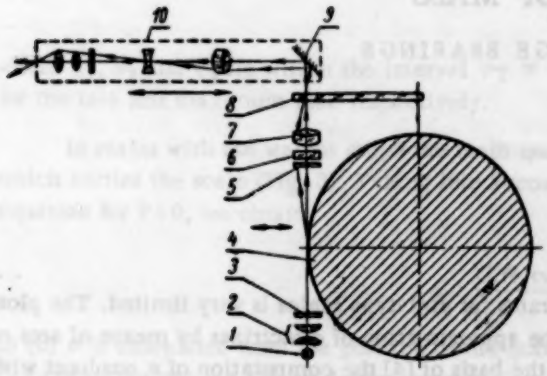

Fig. 1.

The light from lamp 1 passes through a double-lens condenser 2 and illuminates part of objective 7. The other part of the objective is shaded by the contour of detail 4.

The objective projects the contour of the detail onto the plane of a glass scale 8. The image of the detail with the superposed scale calibrations is observed through telescope 10.

The telescope from a levelling instrument NV-1 is used in this device with the eyepiece replaced by an eyepiece micrometer AM9-2 with a magnification of 15. The graduations are calibrated in 0.5 mm but inscribed as millimeters. This is done in order to avoid doubling the measurement results, since in fact radii are measured but read off as diameters. The scale is set in such a manner that its zero calibration is placed above the rotation axis of the detail, which is attained by means of a reference shaft or a micrometer (snap gauge).

The field of vision (Fig. 2) consists of two parts, a bright and a shaded part. The shaded part is the projection of the detail. The boundary between the bright and shaded parts is formed by the generating line of the detail. The

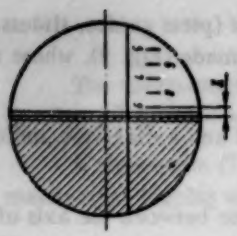

Fig. 2.

calibrations of the glass scale can also be seen in the field of vision. The task of this measurement consists in determining the distance between the edge of the shaded contour and the nearest division on the scale. This distance is measured by means of the bisection lines of the eyepiece micrometer.

Integer millimeters are read off the glass scale, and fractions of a millimeter (tenths and hundredths) off the eyepiece micrometer thimble scale.

The index for setting in a field of vision against the contour of the detail consists of a hairline stretched across the eyepiece micrometer scale and coinciding with the zero calibration of the thimble. Thus, it is not necessary to set the bisection line to the contour of the detail; it is sufficient to set it to the nearest calibration and take the reading.

To compensate for the displacement (of the order of 0.1-0.3 mm) of the slide in cutting, a block gauge 6 is used (see Fig. 1), since the scale is set in a free position of the slide. In order to protect the optics from dust and shavings, protecting glasses 3 and 5 are used. A light filter is placed under protecting glass 3. The equipment consists of 4 parts: the illuminator, objective, telescope with mirror 9, and a supporting bracket.

The illuminator is placed below the slide at a distance of 5-10 mm from the cutting edge of the tool. The objective is centered against the illuminator and fixed to the bracket. The telescope together with its prism is mounted in a jacket with a scale which moves freely in the longitudinal direction. In order to prevent the displacement of the scale in the lateral direction and its skewing, one of its sides is held by flat springs. One end of the scale is firmly fixed to a bracket mounted on the back rest, and the other end is inside the jacket. The bracket is mounted in the tool holder of the slide and carries the telescope with its prism and scale jacket.

The whole of the equipment with the exception of the scale is displaced in either direction together with the slide. The measuring is done during the machining of the details and hence the measuring time is virtually equal to zero.

The operation of this device was investigated under workshop conditions by measuring a stepped shaft with diameters of 200, 300, 400 and 500 mm. The measuring results were compared with micrometer readings.

Investigations have shown that the dispersion of the measuring results amounts to ± 0.02 mm. The total measurement error does not exceed ± 0.04 mm.

At slow rotations of the shaft (up to 40 rpm) it is possible to measure wobble by means of this device.

The defect of the device consists in the complication of measurements when machining is done with a cooling liquid, which has to be cleaned off the optical part of the device.

MEASUREMENTS OF MASS

COMPUTATION OF QUADRANTS WITH KNIFE-EDGE BEARINGS

G. F. Malikov

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The number of papers dealing with the computation of quadrants for dial-type scales is very limited. The plotting of directrixes for various types of scales is dealt with in [1]. The approximation of directrixes by means of arcs of a circle is examined in [2-3]. In the present article we present on the basis of [4] the computation of a quadrant with a knife-edge (Fig. 1).

Let us derive an equation $\rho = \rho(\varphi)$ of the variable loaded arm for a balanced condition of the scale. For simplicity let us assume that the load-carrying band remains vertical during loading. From the balance equation (Fig. 1) we obtain

$$GR\sin\varphi = P\varrho. \tag{1}$$

The condition for a balanced scale has the form

$$P = k\varphi. \tag{2}$$

By eliminating from (1) and (2) the force P, we have

$$\varrho = \frac{GR}{k} \cdot \frac{\sin\varphi}{\varphi}. \tag{3}$$

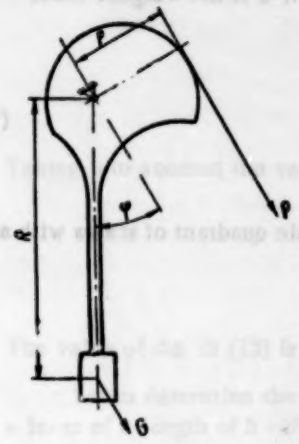

Fig. 1. Quadrant schematic.

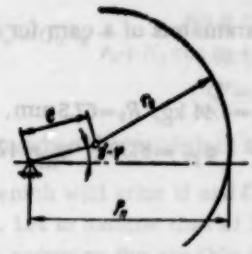

Fig. 2. Schematic of a circular cam.

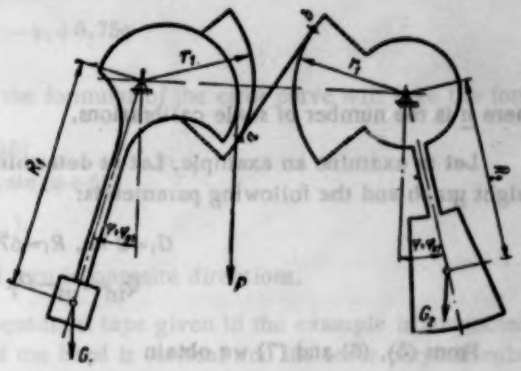

Fig. 3. Schematic of a quadrant for scales with a weight graph.

From the above it is easy to obtain an equation for the directrix of a cam [1]. Normally for technological considerations this equation is approximated by an arc of a circle, which provides an approximately even scale. According to Fig. 2 we have

$$\varrho_n = r_0 + e\cos(\gamma - \varphi). \tag{4}$$

By taking Cartesian coordinates K_1 and K_2 for the center of the circumference we obtain the following equations for determining the values of r_0, K_1 and K_2:

$$r_0 + K_1\cos\varphi_l + K_2\sin\varphi_l = \frac{GR}{k} \cdot \frac{\sin\varphi_l}{\varphi_l}, \quad l = 1, 2, 3, \tag{5}$$

where φ_1, φ_2 and φ_3 lie within the interval $\varphi_T \leq \varphi \leq \varphi_m$. Here φ_T and φ_m are the deflection angles of the pendulum for the tare and maximum load respectively.

In scales with the weight graph the main quadrant is connected by means of band ab with an auxiliary quadrant which carries the scale (Fig. 3). Taking into account that both quadrants are constantly coupled, and using the balance equation for P = 0, we obtain

$$\varrho = \frac{G_1R_1\cos\varphi_{01} + G_2R_2\cos\varphi_{02}}{k} \cdot \frac{\sin\varphi}{\varphi}. \tag{6}$$

In (6) φ is calculated from the position of the quadrants in an unloaded condition. By denoting $G_0R_0 = G_1R_1\cos\varphi_{01} + G_2R_2\cos\varphi_{02}$ we can use (5) for determining r_0, K_1 and K_2. Normally angles φ_{T1} and φ_{T2}, of the main and auxiliary quadrants respectively with a tare load, are given instead of angles φ_{01} and φ_{02} of the same quadrants in an unloaded condition. Hence, let us denote $\Delta\varphi = \varphi_{T1} - \varphi_{T2}$, and obtain from the balance equation with the help of purely kinematic considerations the following expression:

$$\operatorname{tg}\varphi_{02}=-\frac{\sin\Delta\varphi}{\frac{G_2R_2}{G_1R_1}+\cos\Delta\varphi};\quad \varphi_{01}=\Delta\varphi+\varphi_{02}. \tag{7}$$

It is possible to use (6) and (7) when both quadrants are unloaded and become decoupled.

For plotting an error distribution curve we have the following system of equations:

$$Q=G_0R_0\frac{\sin\varphi}{r_0+K_1\cos\varphi+K_2\sin\varphi}-P_T,$$
$$Q'=k_1(\varphi-\varphi_T), \tag{8}$$

where P_T is the tare weight; φ_T is the corresponding angular deflection of the pendulum; Q is the weighed load.

It is convenient to express the error in fractions of a scale calibration:

$$\delta Q=\frac{Q-Q'}{Q_m}n, \tag{9}$$

where n is the number of scale calibrations.

Let us examine an example. Let us determine the parameters of a cam for the basic quadrant of scales with a weight graph and the following parameters:

$$G_1=2\text{ kg},\ R_1=57\text{ mm},\ G_2=1.44\text{ kg},\ R_2=67.5\text{ mm},$$
$$Q_m=P_m-P_T=3\text{ kg},\quad \varphi_{T1}=8°30',\quad \varphi_m=42°.$$

From (5), (6) and (7) we obtain

$$r_0=26.9045\text{ mm},\quad K_1=14.2365\text{ mm},$$
$$K_2=0.12784\text{ mm}. \tag{10}$$

The error determined from (8) and (9) for n = 1250 does not exceed for any value of φ one-tenth of a scale calibration, i.e. it is virtually equal to zero.

In order to determine the variation $\Delta\beta$ of the slope angle β_0 of the band, let us first obtain the equation for curve OO_1O_2 (Fig. 4), described by the end of band O when it remains in an exactly vertical position during loading.

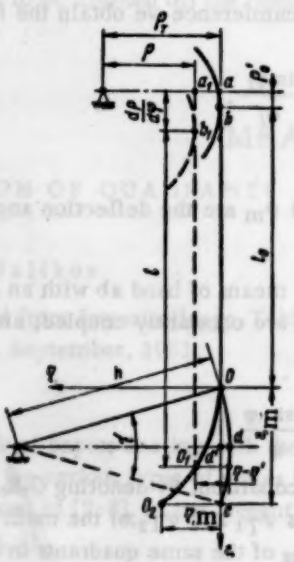

Fig. 4. Displacement of the end of the load-carrying band.

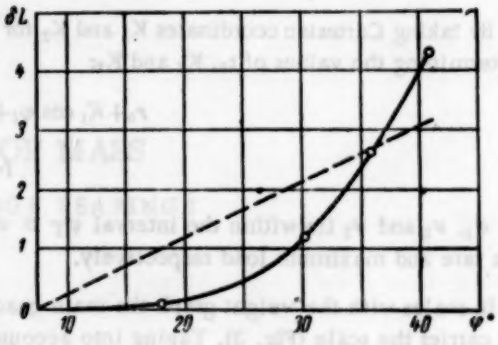

Fig. 5. Error curve.

From [4] we obtain, after transformations,

$$\xi=\frac{G_0R_0}{k}\int_{\varphi_T}^{\varphi_2}\frac{\sin t}{t}\,dt,$$
$$\eta=\frac{G_0R_0}{k}\left(\frac{\sin\varphi_T}{\varphi_T}-\frac{\sin\varphi}{\varphi}\right). \tag{11}$$

The value of ξ can easily be calculated from tables of a sine integral [5]. Approximate expressions for ξ and η have the following form:

$$\xi = \frac{G_0 R_0}{k}(\varphi - \varphi_T), \quad \eta = \frac{G_0 R_0}{k}\left(\frac{\varphi^3}{6} - \frac{\varphi_T^3}{6}\right). \tag{11'}$$

Under working conditions the end of the band is either fixed to lever h of the intermediate mechanism (Fig. 4) or to the transverse member which has a vertical displacement, so that the end of the band moves along curve $\eta' = f(\xi)$, which is determined by the above coupling. By making the usual assumptions in view of the smallness of $\Delta\beta$, it is possible to consider with a high degree of accuracy that the band turns about point b where it is tangential to the directrix of the cam. By replacing angle $\Delta\beta$ with its tangent we obtain

$$\Delta\beta = \frac{1}{6} \cdot \frac{\varphi^3 - \varphi_1^3 - \eta' \dfrac{6k}{G_0 R_0}}{(l_0 - \varrho_0') \dfrac{k}{G_0 R_0} - \varphi_1 + 0.75\varphi}. \tag{12}$$

Taking into account the variation in the slope angle of the band, the formulas of the error curve will take the form

$$Q = G_0 R_0 \frac{\sin\varphi \cos(\beta_0 + \Delta\beta)}{r_0 + K_1 \cos(\varphi + \Delta\beta) + K_2 \sin(\varphi + \Delta\beta)} - P_T; \qquad Q' = k(\varphi - \varphi_T). \tag{13}$$

The value of $\Delta\beta$ in (13) is positive when the pendulum and band turn in opposite directions.

Let us determine the error which will arise if end O of the quadrant tape given in the example is connected to a lever of a length of h = 250 mm. Let us assume that at half-load the band is vertical and the lever perpendicular to it. By replacing with considerable accuracy the arc Ode by chord Od'e we can plot the error curve (Fig. 5) from (9), (12) and (13), assuming that in (12) $\eta' = 0$. It will be seen from Fig. 5 that the value of this error attains four scale calibrations. Therefore, certain parameters must be changed. Of the four quantities r_0, K_1, K_2 and G_0R_0 the last three can be adjusted. Leaving $r_0 = 26.9045$ mm unchanged we determine K_1 and K_2 from

$$\begin{aligned} r_0 + K_1 \cos(\varphi_1 + \Delta\beta_1) + K_2 \sin(\varphi_1 + \Delta\beta_1) &= \varrho_1; \\ r_0 + K_1 \cos(\varphi_2 + \Delta\beta_2) + K_2 \sin(\varphi_2 + \Delta\beta_2) &= \varrho_2, \end{aligned} \tag{14}$$

where φ_1 and φ_2 are two values in the range of $\varphi_T \le \varphi \le \varphi_m$, and the values of $\Delta\beta$ and ρ, which correspond to angles φ_1 and φ_2, as well as r_0 in (14), are known from the previous calculations. Then we obtain from (14)

$$K_1 = 14.0969 \text{ mm}, \quad K_2 = 0.45161 \text{ mm}. \tag{15}$$

By plotting the error curve in a similar manner to the previous one we ascertain that for any value of φ the error does not exceed 0.2 scale calibration, which is completely satisfactory.

The effect of the band slope angle variations (Fig. 6) can also be reduced by selecting an appropriate initial slope angle β_0 for the band in such a manner that $\eta = \eta(\xi)$ and $\eta' = \eta'(\xi)$ are as close to each other as possible. In our example the simplest condition consists in making the end of the lever coincide in its lowest position with point ξ_m, η_m, which corresponds to angle φ_m. For determining the initial slope angle of the tape we have

$$\operatorname{tg}\beta_0 = \frac{\eta_m}{\xi_m}. \tag{16}$$

Expression $\eta' = \eta'(\xi)$ is obtained from the equation of a circle which passes through point $\xi = 0$, $\eta = 0$ and point $\xi = \xi_m$, $\eta = \eta_m$. By expanding this equation in a series and neglecting the smaller terms we have

$$\eta = \frac{\xi^2 + 2\xi_0 \cdot \xi_0}{2\eta_0}, \tag{17}$$

where η_0 and ξ_0 are the coordinates of the center of the circle described by the lever:

$$\eta_0 = \frac{\eta_m}{2} \pm \frac{2h^2}{2+\mu^2}(1-\nu^2),\ \xi_0 = -\frac{\eta_m^2 - 2\eta_m\eta + \xi_m^2}{2\xi_m},$$

where

$$\mu = \frac{\eta_m}{\xi_m},\ \nu = \frac{\xi_m}{n} \cdot \frac{1+\mu^2}{2}.$$

From these formulas we obtain for our example

$$\max \Delta\beta \approx 10'.$$

The variation in the band slope angle is so small that in practice it has no effect in the long run.

Taking the variation of the band slope angle into consideration the expression for ρ assumes the form

$$\rho = \frac{G_0 R_0}{k} \cdot \frac{\sin\varphi}{\varphi} \cos(\beta_0 + \Delta\beta). \tag{18}$$

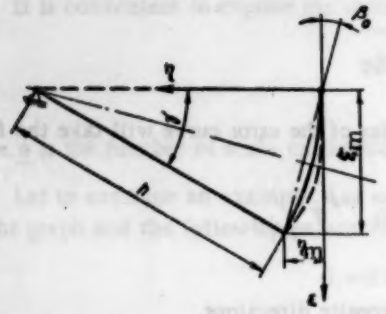

Fig. 6. Determination of the initial angle of the load-carrying band.

If the difference between $\cos\beta_0$ and $\cos(\beta_0 + \Delta\beta)$ amounts to hundred-thousandths of a unit, it becomes possible to determine all the three quantities r_0, K_1 and K_2, by taking $\Delta\beta$ into consideration, from the following system of three linear equations:

$$r_0 + K_1\cos(\varphi_i + \Delta\varphi_i) + K_2\sin(\varphi_i + \Delta\varphi_i) = \frac{G_0 R_0}{k} \cdot \frac{\sin\varphi_i}{\varphi_i}\cos\beta_0,\quad i = 1, 2, 3. \tag{19}$$

In our case the above-mentioned condition is fulfilled and from (19) we have

$$r_0 = 27.6733 \text{ mm},\ K_1 = 13.482 \text{ mm},\ K_2 = -0.01573 \text{ mm}. \tag{20}$$

Error computations show that they amount to hundredths of a scale calibration, i.e. they are virtually equal to zero.

The above computation technique is simple and provides a rapid determination of the required quadrant dimensions. It will be seen from the computations that the variation in the band slope angle may play an important part. However, it is not difficult to take these variations into account. If the quadrant is adjusted separately from the intermediate mechanism lever, it is possible to choose the initial slope angle β_0 of the band from (16) and then compute without taking into consideration the variation $\Delta\beta$ in the band slope angle. If, however, the quadrant is adjusted with the tape connected to the intermediate mechanism lever and the band is vertical in the horizontal position of the lever, it is advisable to compute by taking $\Delta\beta$ into consideration. If the band is fixed to the transverse member which has a vertical displacement, it is recommended to select β_0 in such a manner as to make max $\Delta\beta$ as small as possible.

The fixing of tolerances for the manufacture of the quadrant is of interest. In the above computations we obtained two values for r_0 which differed from each other by almost 1 mm. The adjustable quantities K_1 and K_2 which correspond to one of the values of r_0 differ from those corresponding to the other value by tenths of a millimeter. From the above it is possible to draw the conclusion that excessive accuracy in manufacturing the quadrant is not required, since any possible errors in the dimensions within reasonable tolerances can easily be compensated by adjusting the values of K_1 and K_2 in the range of tenths of a millimeter. This conclusion can easily be explained. For a given value of φ_T we can choose the tare load arbitrarily within certain limits, thus obtaining an infinite number of functions $\rho = \rho(\varphi)$, which provide a uniform scale. Hence, if there exists a single combination of dimensions r_0, K_1 and K_2 which provides a uniform scale with sufficient accuracy, it is possible to obtain a large number of combinations of r_0, K_1 and K_2 which will provide a uniform scale with the same degree of accuracy.

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MECHANICAL MEASUREMENTS

APPROXIMATE COMPUTATION OF THE INERTIA OF A PNEUMATIC SYSTEM CONSISTING OF A PIPELINE AND A SERVOMOTOR

N. F. Broido

Translated from Izmeritel'naya Tekhnika, No. 9,
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The dynamic characteristics of automatic tracking and control systems consisting of pneumatic mass-produced components can be determined both by means of harmonic and discontinuous pneumatic pulses fed to the input of the system.

Harmonic pulses provide more complete characteristics, but their production requires a special generator [1, 10]. Discontinuous pulses provide simplified characteristics, do not normally require a generator, and make it possible to test simultaneously heavy machinery and automation systems.

This work aims at determining by means of discontinuous pulses the dynamic characteristics of the simplest system consisting of a pneumatic line with a diaphragm servomotor. The conclusions thus obtained can also be applied to other systems similar to the above.

Deriving an expression for the system's time constant. The pneumatic lines used in the above systems are characterized by a distributed hydraulic resistance and a gas capacity. When pneumatic pulses are transmitted over these lines the attenuation due to their small diameter is so large that reflected waves are virtually absent, and the propagation time of the direct wave and its distortion become the controlling factors. This greatly simplifies the calculations, providing, nevertheless, results which approach experimental data.

If a compressed air pressure impulse P_{im} is fed to the input of the pneumatic line, its pressure P will vary approximately exponentially with a time constant T_p.

In order to calculate T_p the method of electrical analogy is used, by means of which the distributed hydraulic resistance R_p and gas capacity C_p are replaced by lumped ohmic resistance R_e and capacitance C_e [2, 3].

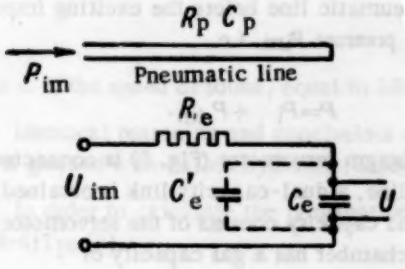


Fig. 1.

Fig. 1 represents the circuit of an electrical model. If a voltage impulse U_{im} is fed to the input of this model, the voltage U across the capacitor terminals will also vary exponentially according to equation

$$U=U_{im}\left(1-e^{-\frac{\tau}{T_e}}\right), \quad (1)$$

where $T_e=R_eC_e$ is the time constant.

The duration of transient processes in pneumatic lines is several times greater than that of electrical lines, and it is therefore necessary to take into account the delay time τ_d in pneumatic lines.

By replacing in (1) U, U_{im}, R_e, C_e and T_e with their proportional quantities of P, P_{im}, R_p, C_p and T_p respectively, we obtain the compressed air pressure equation in a pneumatic line when τ_d is taken into consideration:

$$P=P_{im}\left(1-e^{-\frac{\tau-\tau_d}{T_p}}\right). \quad (2)$$

In [2] experimental curves are provided which confirm the validity of (2). The velocity of the compressed air laminar flow is below that of sound, and the resistance is therefore determined from an equation used for noncompressible liquids.

Resistance R_p is determined from the formula [4]

$$R_p = \frac{128\mu L}{\pi d^4}, \tag{3}$$

and the concentrated gas capacity from an expression in [5]:

$$C_p = \frac{\pi d^2 L}{4P}, \tag{4}$$

where L is the length of the pneumatic line; d is its internal diameter; P is the absolute pressure in the line; μ is the dynamic viscosity of compressed air.

By taking the product of R_p and C_p we obtain the pneumatic line time constant

$$T_p = \frac{32\mu L^2}{d^2 P}. \tag{5}$$

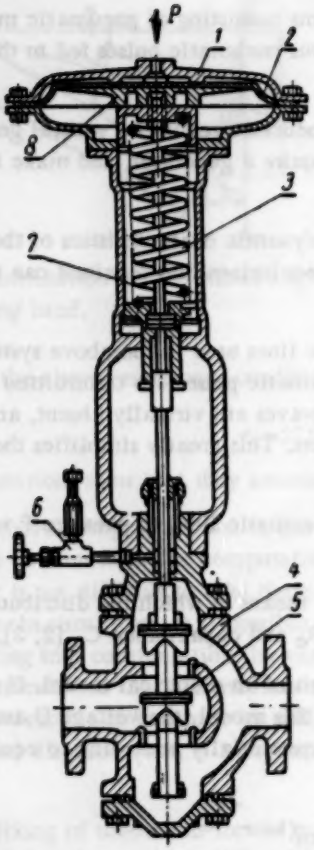
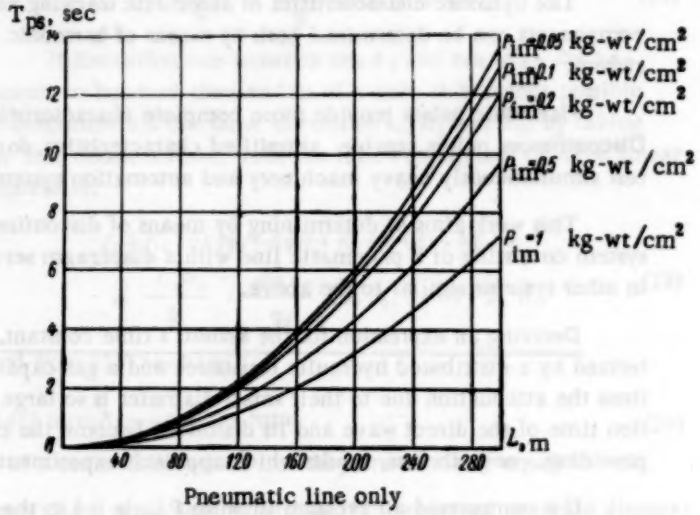


Fig. 2. 1) Cup; 2) diaphragm; 3) spring; 4) valve casing; 5) plunger; 6) lubrication; 7) rod; 8) disc.



Pneumatic line only

Fig. 3. Graph of the relation between T_p and length L of the pipeline.

For further calculations it is convenient to represent pressure P as a sum of two pressures: that of P_i which exists in the pneumatic line before the exciting impulse, and the impulse pressure P_{im}, i.e.

$$P = P_i + P_{im}. \tag{6}$$

If a diaphragm servomotor (Fig. 2) is connected to the pneumatic line, a dual-capacity link is obtained, in which the second capacity consists of the servomotor chamber. This chamber has a gas capacity of

$$C_{s_1} = \frac{V}{P_i + P_{im}} \tag{7}$$

and a so-called hydraulic capacity represented by the formula [5]

$$C_{s_2} = \frac{F_s h_s}{P_{im}}, \tag{8}$$

where V is the volume of the servomotor chamber which is fed with compressed air; F_s is the effective area of the servomotor diaphragm; h_s is the displacement of the diaphragm under the effect of pressure P_{im}.

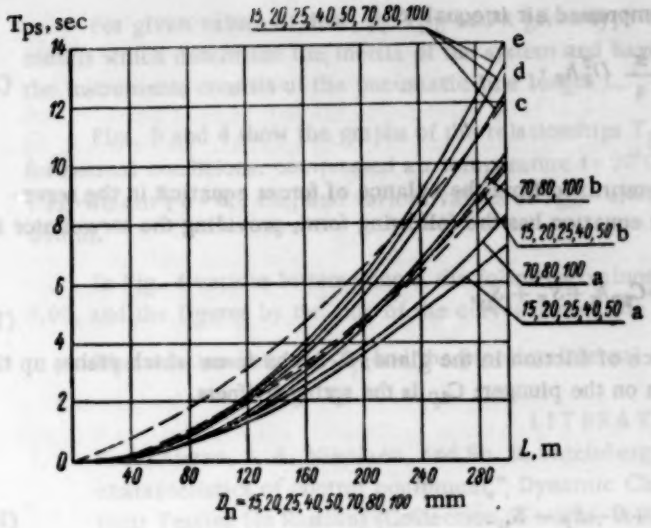


Fig. 4.

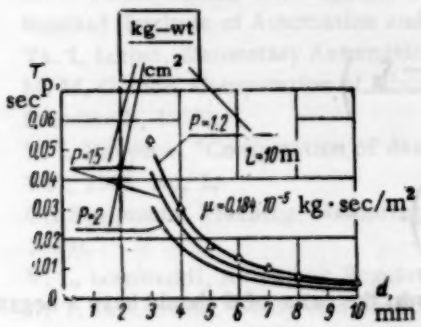


Fig. 5.

Thus the total capacity of the servomotor chamber amounts to

$$C_s = C_{s_1} + C_{s_2}. \tag{9}$$

The diaphgram displacement is small, and C_s can, therefore, be considered concentrated at the end of the pneumatic line. Assuming that the hydraulic resistance between the end of the pneumatic line and the input to the servomotor chamber is virtually equal to zero, we obtain two capacitances C_e and C'_e connected in parallel, where $C'_e = C_e$.

In Fig. 1 capacitance C'_e is shown by a dotted line.

The time constant of this circuit is

$$T_e = R_e (C_e + C_e). \tag{10}$$

Hence, the time constant of the pneumatic line and servomotor system is

$$T_{ps} = R_p (C_p + C_{s_1} + C_{s_2}). \tag{11}$$

By inserting (3), (4), (6), (7) and (8) into (11) we obtain the full expression for the system's time constant:

$$T_{ps} = \frac{128\mu L}{\pi d^4}\left[\frac{\pi d^2 L}{4(P_i + P_{im})} + \frac{V}{P_i + P_{im}} + \frac{F_s h_s}{P_{im}}\right] \tag{12}$$

In (2) the delay time τ_d is included. Theoretically this delay is equal to the sum of the pure delay τ_0 and the transient delay τ_t [3].

The value of τ_t is difficult to calculate. In the majority of practical cases it amounts to a fraction of τ_0, and the full delay time can therefore be determined from formula [2]

$$\tau_d = \frac{L}{\omega}, \tag{13}$$

where ω is the speed of sound, equal to 330.8 m/sec.

Identical reasoning and conclusions are obtained when the pneumatic line is connected to instruments which have a gas, and a so-called hydraulic, capacity.

In order to calculate the propagation time of the complete pulse it is possible to use tentatively the expression $\tau = (3\text{-}6)T_{ps}$ [3].

Calculation of the system's time constants. Our industry produces diaphragm servomotors with differently placed moving parts and varying directions of the effort exercised by the compressed air pressure on the diaphragm. In order to take into account, in computing the inertia of the system, these factors for all types of servomotors an enormous amount of work would have to be done. Hence, we shall determine the inertia only for the most commonly used type of servomotors in which the compressed air stresses the diaphragm from the top, providing the servomotor is mounted normally, i.e. with its diaphragm head pointing upwards, and the counteracting spring exerts an upward pressure on the diaphragm. This class comprises the following types of servomotors: 25ch30nzh, 25ch32nzh, 25s48nzh, 25s50nzh, 25s52nzh, 25s54nzh, 25s40 nzh; 25s42nzh, MIM, MRKCh, K, KR, KYa, KRYa, PRK and others [6].

The position of the details and the direction of the compressed air pressure on the diaphragm affect the forces balance equation in the servomotor. Let us examine in greater detail the second and third terms in the brackets of expression (12).

The volume V of the chamber which is fed by compressed air is equal to

$$V = \frac{\pi}{4} D_1^2 h_s, \tag{14}$$

where D_1 is the diameter of the servomotor cup.

The value of h_s varies with pressure P_{im} and is determined from the balance of forces equation in the servomotor. For the servomotor class under consideration this equation has the following form, providing the servomotor is normally mounted:

$$P_{im} F_s + G = C_{sp} h_s + S_T + S_u, \tag{15}$$

where G is the weight of the moving parts; S_T is the force of friction in the gland; S_u is the force which pushes up the rod and is due to the unbalanced pressure of the medium on the plunger; C_{sp} is the spring stiffness.

Hence

$$h_s = \frac{P_{im} F_s + G - S_T - S_u}{C_{sp}}, \tag{16}$$

the second term assumes the form

$$\frac{\pi D_1^2}{4 (P_1 + P_{im})} \left(\frac{P_{im} F_s + G - S_T - S_u}{C_{sp}} \right). \tag{17}$$

and the third term becomes

$$\frac{F_s}{P_{im}} \left(\frac{P_{im} F_s + G - S_T - S_u}{C_{sp}} \right). \tag{18}$$

If the servomotor is mounted with its diaphragm head pointing downwards, the value of G should have a negative sign.

The friction force S_T of the gland with a lubricator is obtained from formula [7]

$$S_T = 1.5 \cdot 0.025 \cdot d_r l, \tag{19}$$

where 0.025 kg-wt/cm^2 is the specific friction force on the sealed surface of the rod, a value which depends but little on the static pressure in the valve, at least in the range of 3-25 kg-wt/cm^2; d_r is the diameter of the rod, cm; l is the length of the gland, cm.

The force S_u depends on the pressure of the medium which flows through the valve. If S_u rises the displacement of the diaphragm decreases and, hence, the second and third terms as well as T_{ps} become smaller. If we assume that $S_u = 0$, the value of T_{ps} attains a maximum. This corresponds to the most unfavorable case when the inertia of the system is at a maximum.

The effective area of the servomotor diaphragm (in cm^2) is determined from the expression [7]

$$F_c = \frac{\pi}{12} (D_1^2 + D_1 D_2 + D_2^2), \tag{20}$$

where D_1 is the diameter of the cup, cm; D_2 is the diameter of the disc, cm.

In order to simplify the calculations it is possible to neglect force S_T for $P_{im} \geq 0.05$ kg-wt/cm^2, since the ratio $(P_{im} F_s + G)/C_{sp}$ amounts to a few percent only.

Thus, after simplifications equation (12) assumes the form

$$T_{ps} = \frac{128 \mu L}{\pi d^4} \left[\frac{\pi d^2 L}{4 (P_1 + P_{im})} + \right.$$
$$\left. + \frac{\pi D_1^2}{4 (P_1 + P_{im})} \left(\frac{P_{im} F_s + G}{C_{sp}} \right) + \frac{F_s}{P_{im}} \left(\frac{P_{im} F_s + G}{C_{sp}} \right) \right]. \tag{21}$$

For given values of d, μ, P_l, P_{lm} and a given type of instrument or servomotor, one of the most important parameters which determine the inertia of the system and have a decisive effect on its construction and the location of the instruments consists of the pneumatic line length L.

Figs. 3 and 4 show the graphs of the relationships $T_p = f(L)$ and $T_{ps} = f(L)$ for various values of P_{lm} calculated for normal conditions: compressed air temperature t = 20°C; the dynamic viscosity $\mu = 0.184 \cdot 10^{-6}$ kg · sec/m²; P_l = 1 kg-wt/cm²; d = 0.6 cm; and various values of P_{lm} = 0.05, 0.1, 0.2, 0.5 and 1 kg-wt/cm², with L between 0 and 300 m.

In Fig. 4 various letters denote the following values of P_{lm}, kg-wt/cm²: a = 1, b = 0.5, c = 0.2, d = 0.1 and e = 0.05, and the figures by the side of the curves denote the nominal valve openings D_n in mm.

The relation between T_p and the pipeline internal diameter d is shown in Fig. 5.

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INVESTIGATING THE OPERATION OF WIRE STRAIN GAUGES WITH SPHERICAL ELASTIC ELEMENTS

A. M. Kazanskii

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In experimental solutions of certain scientific and technical problems transducers are used (dynamometric elements) which consist of elastic spheres with wire grids glued onto them.

Such transducers are used for investigating static and dynamic loads on rolling mill rolls, on foundations of travelling and column cranes, on excavators, on roller and wheeled propelling devices of machines, on working elements of crushers, on ball bearings, as well as in many other instances.

Transducers with elastic spheres possess several unquestionable advantages: their capacity to register considerable loads for relatively small sizes and to provide a strictly determined direction of the measured force; their linear characteristics in a range extending from the smallest to the largest loads, which almost attain the elastic limit; the simplicity and low cost of their construction due to the utilization of balls produced by the ball bearing industry; and the high precision of their dimensions, which the GOST (All-Union State Standard) 3722-54 specifies, for instance, for 50 mm grade 6 steel balls as a deviation from a spherical shape not exceeding 0.04 mm.

The defects of these transducers consist of the following: they can only register compression loads; it is difficult to keep them in a fixed position, especially for impact loads which displace them from their original position; the lower limit of accurately measurable loads amounts to some $0.1 \cdot d^2$ (kg-wt), where d is the diameter of the elastic sphere; this limit is sometimes insufficiently low. The diameter of the sphere is usually made four times the base of the wire grid.

It is obvious that the first defect is inherent and can only be overcome by additional elements, which transmit tensile efforts to the sphere in the form of compression loads. This is not always convenient, since it deprives the transducer of the first of its aforementioned advantages, namely, its compactness for large loads.

The effect of the remaining two defects was considerably reduced as the result of the investigations carried out by us*.

Until recently spherical transducers were used with a flat along their diameter plane. This flat reduced the class of surface finish and formed a narrow cylindrical strip, thus making it easier to glue wire grids onto it. In addition the flat was often used for preventing the sphere from turning under dynamic loads.

In order to check the effectiveness of the flat for improving the adhesion of wire grids, we fixed them (in our experiments in 1957) by means of an acetone-celluloid adhesive directly onto the spherical surface without changing its finish. Two years later the characteristics of the elastic spherical transducer had not changed.

Numerous experiments carried out since with spheres without flats make it possible to assert that for the overwhelming majority of applications of spherical elastic transducers it is possible to glue the wire grids directly onto the spherical surface without in any way reducing their reliability.

The absence of flats simplifies the manufacture of transducers and provides far greater flexibility for the location of wire grids, which is often very important from the constructional point of view.

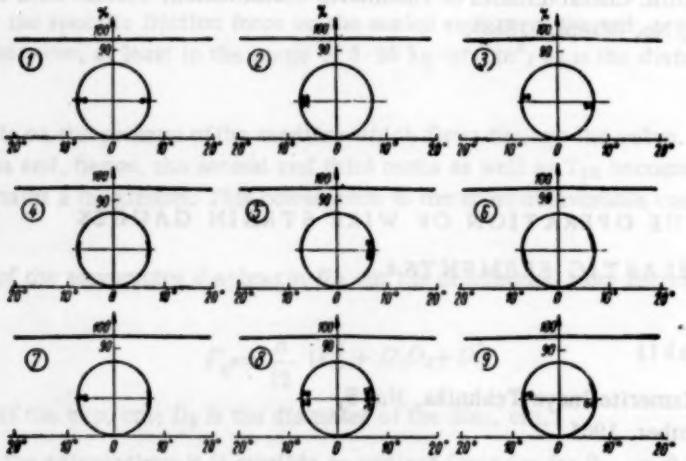

Fig. 1. Different ways of fixing wire grids, and graphs of instrument readings when the sphere is rotated in the plane of the drawing (group A).

* Investigations were conducted by us in conjunction with M. L. Shutov of the All-Union Scientific Research Institute of Road Construction Machinery in 1958-59.

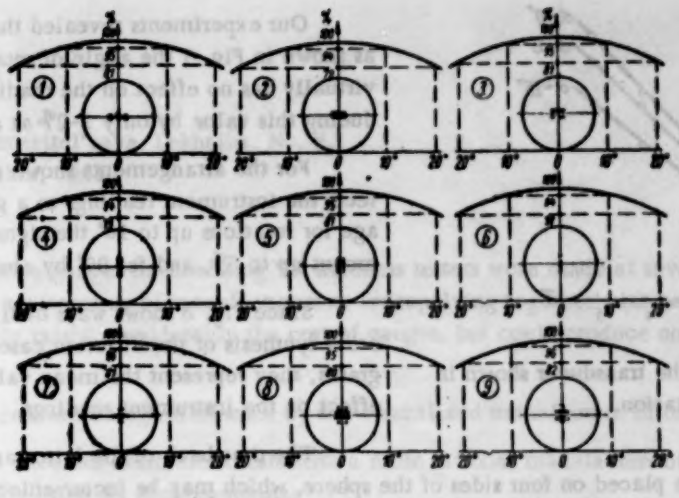

Fig. 2. Different ways of fixing wire grids, and graphs of instrument readings when the sphere is rotated in the plane of the drawing (group B).

Experiments have shown that at any point on the surface of the sphere which is compressed at its poles, compression deformations occur in the meridional direction and tensile deformations along the diametric circumference passing through the same point. The compression stresses are slightly smaller than the tensile stresses (for a sphere 3" in diameter this difference amounts to 25%).

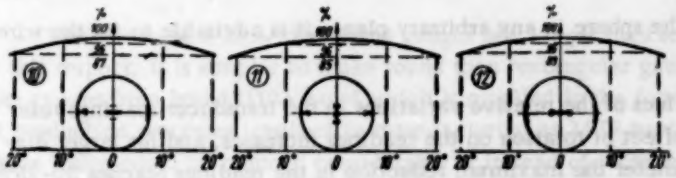

Fig. 3. Different ways of fixing wire grids, and the graphs of instrument readings when the sphere is rotated in the plane of the drawing (group C).

Fig. 4. Graph of the instrument readings when the sphere is rotated in the indicated plane.

Owing to the existence of deformation of different signs and the absence of flats it becomes possible to provide a more sensitive measuring bridge and to measure under the same conditions loads which are only half their previous value.

At the same time it is possible to dispense with special balancing wire grids and obtain an improved temperature error compensation. Moreover, the existence in the bridge arms of transducers which have deformations of opposite signs makes it possible to provide a circuit whose balance can be checked (by means of a switch) without unloading the transducer. This is especially valuable when large loads are being measured.

Our investigations were also concerned with determining the effect of the angle of rotation of the elastic sphere with respect to the effective load for various locations of the wire grids on the surface of the sphere.

Figs. 1, 2 and 3 show the most promising ways of gluing the wire grids onto the sphere.

Investigations were carried out by means of an MPO-2 oscilloscope with a type 5vibrator, an 8AN4-7M amplifier, and an ISD-2 IMASh set constructed by the Central Design Bureau of the USSR Academy of Sciences, which provided strain measurements of $\epsilon = \pm 0{,}0750\%$.

Each transducer was loaded up to 7.5 tons. Readings were taken at 5° intervals of its rotation in the stated plane up to an angle of 20°. The sphere was rotated in both directions. Having assumed the value of the bridge signal for all the spheres' initial setting to be equal to 100%, we obtained the graphs relating the value of this signal to the angle of rotation.

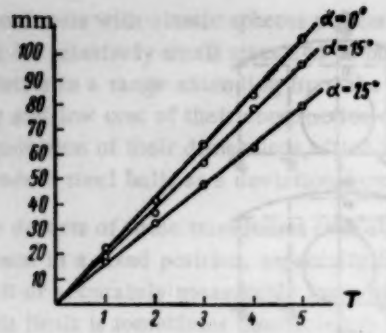

Fig. 5. Calibration graphs of the transducer shown in Fig. 4 for various angles of rotation.

Our experiments revealed that when the grids are fixed as shown in Fig. 1 the angle of rotation in the tested range virtually has no effect on the readings of the instrument, reducing this value by only 1-2% at an angle of 20°.

For the arrangements shown in Fig. 2 the rotation affects the instrument readings to a greater extent. On an average for rotations up to 10° the signal is decreased by an amount up to 5%, and for 20° by about 20%.

Since Fig. 3 shows ways of fixing the wire grids which are a synthesis of the different cases shown in previous diagrams, they represent the mean value of the rotation angle effect on the instrument readings.

The drawback of the latter arrangements consists in the fact that the wire grids are placed on four sides of the sphere, which may be inconvenient from the constructional point of view.

Experiments have shown that the variation of the rotation plane (Fig. 4) also affects the readings, and for a displacement of 45° in the plane of rotation the errors amount to a mean value between that produced by the grid fixed in the manner shown in Fig. 1 (8) and that shown in Fig. 2 (8).

The latter transducers were also tested with two grids in each arm of the bridge. As one would expect, the rotation of the sphere produced the same errors as for one grid in each arm. A further increase in the number of wire grids in the arms of the bridge does not improve the transducer characteristics, since the grids occupy an intermediate position between those given above, and we shall obtain intermediate characteristics between those shown for transducers 8 and 9 (Figs. 1 and 2).

Since it is impossible to prevent the rotation of the sphere in any arbitrary plane, it is advisable to fix the wire grids in the manner shown in Fig. 3.

It should be noted that in the above graphs the values of the relative variations in the transducer readings refer to a sphere 3" in diameter. For smaller diameters the effect of rotation on the readings increases, and for larger diameters it decreases. Thus, for spheres 30-40 mm in diameter the maximum reduction in the readings reaches 30-25% for the rotation angle of 20°.

Thus, if the rotation of transducer spheres of almost any diameter is limited to ±5° in the most unfavorable plane, the measurement error will not exceed 1-3%, and it will always tend to reduce the reading.

It should be noted that in our experiments we discovered yet another important quality of the elastic spherical transducers, namely the linearity of their characteristics for any rotation angle of the sphere with respect to the effective load in any plane.

Fig. 5 carries the calibration graph of the transducer shown in Fig. 4 for rotation angles of 15 and 25° with respect to the initial position.

The above test results provide a reasonable basis for choosing the manner of locating wire grids and placing the elastic spheres in the working position for each specific case.

HARDNESS GAUGES

A. I. Suvorov

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Until recently reference gauges for checking TK hardness testers were made at several plants. They were mainly intended for meeting the requirements of manufacturers or for supplying together with newly made hardness testers. This state of affairs not only raised considerably the cost of gauges, but could produce nonuniformity of hardness units in the country.

At present these defects are being eliminated by the centralized manufacture of hardness gauges.

In this connection it becomes desirable to establish a more rational manufacture of hardness gauges and find more effective ways of using them for measurements.

It is customary in double-shift working to make some 2500-3000 measurements with a TK hardness tester. In making these measurements it is necessary to check the instrument periodically by comparing it with a reference hardness gauge. In the two shifts some 40-50 check indentations have to be made on a hardness gauge.

On the basis of the over-all dimensions of hardness gauges and the circular (cylindrical) templet with a 10 mm hole it is possible to calculate that a rectangular gauge can carry a maximum number of 345 scale C and A indentations, and 126 scale B indentations, whereas a round gauge will carry 395 scale C and A and 144 scale B indentations. With a TK hardness tester fully utilized in two-shift working, a rectangular hardness gauge will last 8 days on C and A scales, and 3 days on a B scale, whereas a round gauge will last 9.5 days on C and A scales and 3.5 days on a B scale.

The above data show that round gauges last longer than rectangular gauges, and are therefore more efficient in this respect. It is simpler to make round than rectangular gauges. The Ivanovo GZIP Plant makes rectangular hardness gauges from brand U10A steel which is supplied in the form of a strip with a cross section of 260 x 16 mm. In the 21 production processes involved in manufacturing an MTR hardness gauge the plant loses about 63% of the metal. These losses could be reduced considerably if, instead of rectangular, round gauges were to be manufactured. The production of round gauges requires less milling, simplifies cutting, polishing and smoothing edges whose number is reduced from 12 to 4, and lends itself to a more productive and inexpensive machining. The round cylindrical shape of hardness gauges improves their heat treatment, since their uniform heating up and cooling during annealing and hardening raise their uniformity with respect to hardness.

However, there exists the opinion that rectangular hardness gauges are preferable to round gauges. This school of thought maintains that round gauges are made of rods whose hardness may not be uniform owing to differences in the chemical composition, structure and quality of metal in the center and the periphery of the rod.

In our opinion such reasons for rejecting round hardness gauges under centralized mass production conditions are not justified. At present it is possible to produce rods specially for hardness gauges, maintaing the chemical and structural uniformity of metal over the whole cross section of the rod.

The uniformity of hardness gauges can be attained by means of experiments which can be carried out much better in view of the centralized mass production of these gauges at one plant. It should be noted that the facilities for carrying out this work have not, as yet, been properly utilized. For instance, approval has not been obtained for a method of raising the uniformity and reducing the dispersion of hardness gauge readings by a double cooling to −20° and −70°C, as recommended at the International Conference on Hardness (Bremen, September 22-23, 1955, statement of the Japanese representative Akashi).

Another factor which is just as important for rationalizing hardness measurements consists of the more effective use of hardness gauges, since their life is very short owing to their rapid wear.

In the existing hardness gauges only the upper working surface is used for checking hardness testers, whereas the metal and the technology of their heat treatment provide the required conditions for also using the bottom surface as a working surface. This will double the life of hardness gauges and thus reduce their required production.

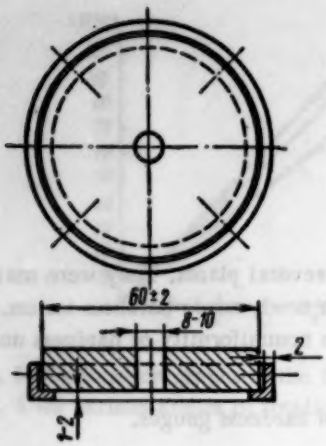

Fig. 1.

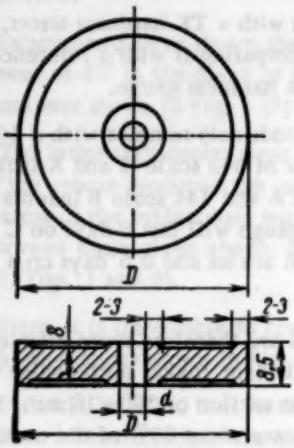

Fig. 2.

In order to be able to use the bottom testing surface for test purposes, it should be kept intact while the upper surface is being utilized. This can only be attained if the lower surface does not touch the bearing table of the instrument when the upper surface is being subjected to indentations.

It is suggested that for this purpose the hardness gauge should be placed on the instrument table in a special holder which would prevent its lower surface from touching the table (Fig. 1). The hardness gauge should rest on the holder with its edges 2.5 mm wide, which should not be used for indentations. When the upper surface has been fully utilized the gauge is removed from the holder, turned over and reset in the holder with the help of set screws (after fitting-in by means of a "pin", inserted in the gauge hole). Production measurements have shown that the sagging of the bottom unindented surface of the hardness gauge is of the order of 0.005-0.010 mm when the upper surface is indented by means of a diamond cone or ball. It is, therefore, necessary to have a gap of 0.3-0.5 mm between the table and the lower surface of the gauge, in order to protect it from any damage while the upper surface is being indented. The assumption that the hardness uniformity of the gauge (dispersion of readings) will be affected by the sagging due to the force of 150 kg-wt produced by the instrument tip is not justified, since with a hardness gauge 8 mm thick the amount of deformation is so small that it need not be taken into account.

In order to be able to use in a similar manner both the upper and lower surfaces of the gauge for test purposes it is possible, instead of using a holder, to change the shape of the hardness gauge, providing both its surfaces with rims 0.2-0.3 mm high and 2-3 mm wide (Fig. 2).

The problem of utilizing both the upper and lower surfaces of hardness gauges for testing purposes requires further experimental work in order to find optimum values for the height and width of the edges; however, there are reasonable grounds to expect a successful solution of this problem.

DETERMINING THE DAMPING OF ELASTO-PLASTIC MATERIALS

G. S. Rosin

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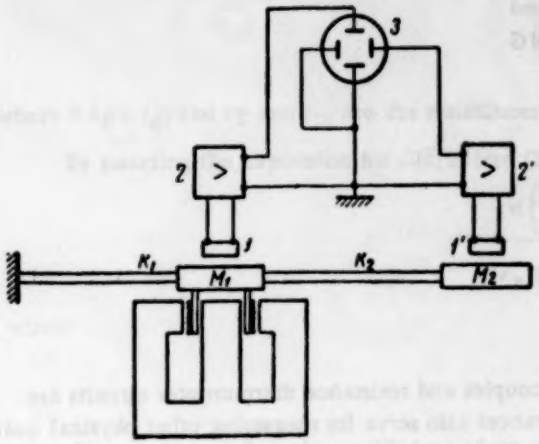
p. 21, September, 1961

If damping η in elasto-plastic materials (rubber, foam plastic) is determined at the natural oscillation frequency of the tested sample [1], it will be determined for that frequency only. In order to determine the damping at other frequencies it is necessary to change the natural frequency of oscillation, which will require a large number of samples. Even then it is impossible to obtain measurements over a sufficiently wide frequency range. The study of forced oscillations makes it possible to determine damping by means of one sample at virtually any frequency. Below we describe a new method of determining losses.

Let us assume we have an oscillatory system which has one degree of freedom and consists of an elastic element with stiffness k_1 and mass M_1, whose oscillations are induced by means of an electrodynamic or electromagnetic transducer (see figure).



Let us attach to that system the tested sample which has stiffness k_2 and carries at its end mass M_2. We shall then obtain an oscillatory system with two degrees of freedom. If we denote by $\dot{x}_1$ the velocity of mass M_1 and by x_2 the velocity of mass M_2, we shall be able to write for this system that [2]

$$\dot{x}_1 = \frac{j\omega(\kappa_2 - \omega^2 M_2) Q e^{j\omega t}}{(\kappa_1 + \kappa_2 - \omega^2 M_1)(\kappa_2 - \omega^2 M_2) - \kappa_2^2}; \quad (1)$$

$$\dot{x}_2 = \frac{j\omega \kappa_2 Q e^{j\omega t}}{(\kappa_1 + \kappa_2 - \omega^2 M_1)(\kappa_2 - \omega^2 M_2) - \kappa_2^2}, \quad (2)$$

where ω is the angular velocity; Q is the amplitude of the external force.

Let us now find the ratio of velocities $\dot{x}_1/\dot{x}_2$:

$$\frac{\dot{x}_1}{\dot{x}_2} = \frac{\kappa_2 - \omega^2 M_2}{\kappa_2}. \quad (3)$$

If the tested sample has losses we should include in the formula a complex expression for elasticity:

$$\kappa_2 = \kappa_{20}(1 + j\eta), \quad (4)$$

where $\eta = \vartheta/\pi$, and ϑ is the logarithmic decrement. We can now write

$$\frac{\dot{x}_1}{\dot{x}_2} = \frac{1 - \frac{\omega^2 M_2}{\kappa_{20}} + \eta^2 + j\frac{\omega^2 M_2}{\kappa_{20}}\eta}{1 + \eta^2}. \quad (5)$$

It can easily be shown that the phase angle of this expression is equal to the phase difference between $\dot{x}_1$ and $\dot{x}_2$.

By denoting this angle by φ, we find

$$\eta = \left[(1 + \eta^2) \frac{\kappa_{20}}{\omega^2 M_2} - 1 \right] \operatorname{tg} \varphi. \quad (6)$$

Thus, having determined the phase difference angle φ between velocities $\dot{x}_1$ and $\dot{x}_2$ it is possible to determine η by the method of successive approximations. We first find the value of η for $\eta^2 \ll 1$ and then, having inserted this value of η into the sum $1 + \eta^2$, we find the final value of η and ϑ.

The phase difference angle can be determined in the following manner (see figure). Moving-coil transducers 1 and 1' are placed near masses M_1 and M_2 and produce signals which are proportional to their velocity. These signals are amplified by two identical amplifiers 2 and 2', and are fed to a cathode-ray oscilloscope 3, for determining the phase difference angle (by any known method).

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THERMOTECHNICAL MEASUREMENTS

UTILIZATION OF THERMISTORS FOR CORRECTING DIFFERENTIAL TEMPERATURE-DIFFERENCE MEASURING CIRCUITS

M. A. Kaganov and Yu. L. Rozenshtok

Translated from Izmeritel'naya Tekhnika, No. 9, pp. 22-25, September, 1961

For direct measurements of temperature differences, thermocouples and resistance thermometer circuits are widely used. Differential circuits for measuring temperature differences also serve for measuring other physical quantities. Measurements of small temperature differences are required, for instance, in recording radiation fluxes (thermoelectric pyrometers, actinometers, etc.), and in conjunction with various other thermal converters.

The drawback of the above circuits consists in the effect of absolute temperature on sensitivity, which prevents accurate measurements of temperature differences ΔT in the cases when temperature T varies over wide ranges. For accurate measurements of ΔT it is necessary to determine the value of T and apply appropriate corrections.

In the present work we describe methods for compensating the variations in the sensitivity of differential circuits due to changes in absolute temperature by using thermistors as correcting elements.

Let us examine circuits for measuring temperature differences by means of thermal elements and metal resistance thermometers.

Correcting element in a differential thermocouple circuit. It is known [1] that the thermal emf E of the majority of thermocouples can be approximated over a limited temperature range T of the hot junction by a second-degree polynomial (for a cold junction temperature of 0°C):

$$E=\alpha T+\beta T^2, \qquad (1)$$

where α and β are constant coefficients.

In measuring a temperature difference $\Delta T = T_2 - T_1$ the thermal emf is

$$\Delta E = \left(1+\frac{2\beta}{\alpha}\overline{T}\right)\alpha\Delta T, \qquad (2)$$

where $\overline{T}=(T_1+T_2)/2$ is the mean value of the temperature of the two junctions.

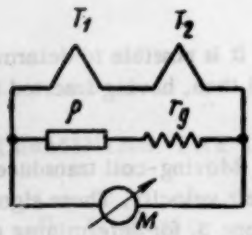

Fig. 1.

It will be seen from (2) that the coefficient which determines the sensitivity of the thermocouple in measuring the temperature difference ΔT is a linear function of temperature. In the temperature range of −50° to + 50°C coefficient $2\beta/\alpha$ of the linear term is equal for copper-constantan electrodes to $2.4 \cdot 10^{-3}$ deg^{-1}, for platinrhodium-platinum electrodes to $2.9 \cdot 10^{-3}$ deg^{-1}, and for chromel-copel electrodes to $1.2 \cdot 10^{-3}$ deg^{-1}. Thus, the sensitivity of differential thermocouples varies approximately by 10-30% for every 100° variation in the mean temperature of the junctions. This sensitivity variation of differential thermocouple circuits can be compensated by connecting in parallel with the measuring instrument M (galvanometer, millivoltmeter) a correcting network consisting of resistance ρ with a negative temperature coefficient (for instance, a thermistor) and a fixed resistance r_g (Fig. 1). The correcting thermistor is kept at the temperature of the medium in which the measurements are made.

Both here and subsequently the use of a fixed resistance provides more flexible variation of the temperature sensitivity in the circuit. Moreover, the method of connecting this resistance (in series or parallel with the thermistor) is determined by the maximum sensitivity of the circuit.

The principle of operation of this circuit consists in the fact that the thermocouple's rising sensitivity with temperature is compensated by the falling resistance of the compensating circuit which shunts the measuring instrument. The parameters of the correcting circuit are calculated in the following manner. The current in the measuring instrument is

$$i = \frac{\Delta E}{r_T + r_m + \frac{r_T r_m}{R}}, \tag{3}$$

where $R = \rho + r_g$; and r_T and r_m are the resistances of the thermocouple and the measuring instrument respectively.

By inserting the expression for ΔE[(2)] into (3) we obtain

$$i = \frac{\alpha\left(1 + \frac{2\beta}{\alpha}\overline{T}\right)\Delta T}{(r_T + r_m)\left(1 + \frac{r_1}{R}\right)} = K(\overline{T})\Delta T, \tag{4}$$

where

$$r_1 = \frac{r_T r_m}{r_T + r_m}.$$

The condition when the coefficient of proportionality $K(\overline{T})$ is independent of temperature over a certain given range of mean temperature variations,

$$K(\overline{T}) = \text{const}, \tag{5}$$

can be found by means of P. L. Chebyshev's method of best approximations [2]. This method was previously used for calculating thermistor circuits [3].

It will easily be seen that $K(\overline{T})$ can be represented with sufficient accuracy by a second degree polynomial of $\overline{T} - T_0$, where T_0 is the mean range of possible variations of $\overline{T}$. Thus, conditions (5) will be fulfilled according to the method of best approximations when the coefficient of the linear term of the expansion becomes zero, i.e.

$$\frac{d}{d\overline{T}} K(\overline{T}) \Big|_{\overline{T} = T_0} = 0. \tag{6}$$

From condition (6) the following relation is deduced:

$$r_g = \frac{r_1}{2}\left(\sqrt{1 + \frac{2\varrho(T_0)\gamma\alpha}{r_1\beta}} - 1\right) - \varrho(T_0), \tag{7}$$

where $\gamma = \left|\frac{1}{\varrho}\frac{d\varrho}{dT}\right|_{T=T_0}$ is the absolute value of the thermistor temperature coefficient. The maximum value of the thermistor which satisfies condition $r_g \geq 0$ becomes equal to

$$\varrho_{max}(T_0) = r_1\left(\frac{\gamma\alpha}{2\beta} - 1\right). \tag{8}$$

If the resistance r_1 is small (ohms or tens of ohms), relatively small thermistors (for instance, MMT-8 or MMT-9) [4] should be used for compensation purposes.

The variation of the thermocouple sensitivity with temperature can also be compensated by connecting a thermistor with a positive temperature coefficient in series with the thermocouple. However, in this case the general sensitivity of the circuit is greatly reduced.

Let us now give an example of computing temperature compensation for a differential chromel-copel thermocouple circuit operating in the range of −50° to + 50°C. The thermocouple resistance is 12 ohm, that of the measuring instrument 36 ohm, the MMT-9 thermistor temperature coefficient at 0°C is 3.6% per 1°, and the absolute resistance of the thermistor is $\rho \mid_{\overline{T}=0} = 81.1$ ohm. From (7) we obtain $r_g = 63.1$ ohm. By inserting this value of r_g into the expression for $K(\overline{T})$ we find that it varies in the range of −50° to + 50°C by not more than 1.2%. The application of a differential chromel-copel thermocouple without compensation in the same temperature range provides a deviation of the sensitivity from its mean value by ± 6% (Fig. 2). Thus, the use of a correcting element makes it possible to reduce the error due to the variation of the differential thermocouple sensitivity with the absolute temperature by a factor of 5 without a noticeable reduction in the sensitivity of the circuit as a whole.

A similar compensation principle can be used in a differential circuit consisting of two thermocouples connected in parallel with the measuring instrument. Such a circuit is used for measuring temperature differences along sample electrical conductors [5].

Correcting element in a differential bridge circuit with metal resistance thermometers. It is known that the sensitivity of differential circuits for measuring temperature differences by means of metal resistance thermometers, or that of differential bolometer circuits, varies with temperature [6].

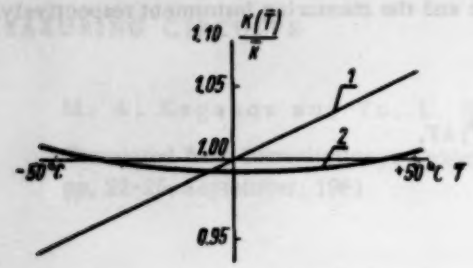

Fig. 2. Relative variations of differential thermocouple sensitivity with temperature. 1) Without compensation; 2) with compensation.

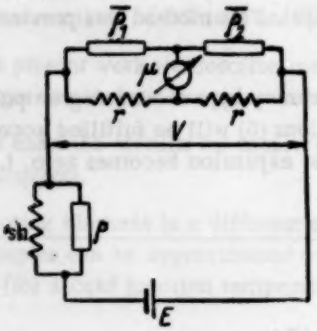

Fig. 3.

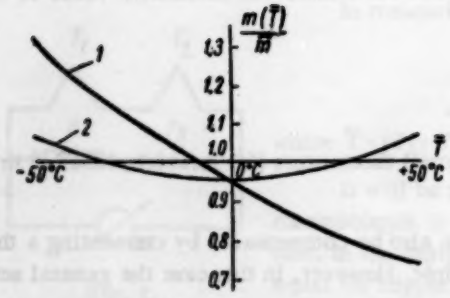

Fig. 4. Relative variations of the sensitivity of a differential bridge with a metal resistance thermometer. 1) Without compensation; 2) with compensation.

Let us examine a symmetrical differential bridge whose arms contain metal resistance thermometers $\bar{\rho}_1$ and $\bar{\rho}_2$ registering temperatures T_1 and T_2, and which has two fixed resistors r. Then current i in the measuring diagonal of the bridge will be

$$i = U \frac{\bar{\varrho}_1 - \bar{\varrho}_2}{2\bar{\varrho}\,(\bar{\varrho} + r + 2r_m)}, \tag{9}$$

where U is the voltage across the bridge supply diagonal; r_m is the resistance of the measuring instrument.

In the denominator of (9) we can neglect the difference in the resistance of the thermometers in view of their small temperature coefficient.

Since the temperature characteristic of the metal resistance thermometers is linear it is possible to re-write (9) in the form

$$i = U \frac{\bar{\varrho}_0 \beta_t}{2\bar{\varrho}\,(\bar{T})\,[\bar{\varrho}\,(\bar{T}) + r + 2r_m]} \Delta T, \tag{10}$$

where β_t is the temperature coefficient of resistance thermometers, and

$$\bar{\varrho}_0 = \bar{\varrho}\big|_{\bar{T}=0°C}.$$

It will be seen from (10) that with a rising temperature, $\bar{\rho}\,(\bar{T})$ increases and the circuit sensitivity drops. The above effect is similar to that obtained with differential thermocouples and prevents accurate measurements of ΔT over a wide range of absolute temperature variations.

In order to compensate the sensitivity variations with temperature of a differential bridge circuit it is possible to connect into its supply circuit a correcting network with a thermistor ρ at the temperature of the surrounding medium, and a fixed resistor r_{sh} in parallel with it (Fig. 3).

With an appropriate selection of the correcting network parameters the bridge circuit sensitivity due to variations in the metal thermometer resistance can be compensated with sufficient accuracy by the rise in the voltage at the bridge input.

In the presence of a correcting element the current through the measuring diagonal of the bridge can be represented by

$$i = E \frac{\bar{r}\bar{\varrho}_0 \beta_t \Delta T}{\left[2\bar{\varrho}r + \dfrac{\varrho r_{sh}}{\varrho + r_{sh}}(\bar{\varrho} + r)\right](\bar{\varrho} + r + 2r_m)} = m(\bar{T})\,\Delta T. \tag{11}$$

For coefficient $m(\bar{T})$ to be independent of temperature, it is necessary as in the case of thermocouples that, in accordance with P. L. Chebyshev's method of best approximations,

$$\left.\frac{dm}{d\bar{T}}\right|_{\bar{T}=T_0}=0. \tag{12}$$

This condition makes it possible to calculate resistance r_{sh} for given bridge circuit parameter and thermistor values. Thus

$$r_{sh}=\bar{\varrho}\frac{1+\frac{2r\,(2A-r)}{A\varrho}+\sqrt{1+\frac{2r\epsilon(A^2-r_m^2)(2A-r_m)}{\bar{\varrho}\varrho A^2}}}{\frac{(A^2-r_m^2)\epsilon}{A}-\frac{2(2A-r)r\varrho}{\varrho A}-2\bar{\varrho}}, \tag{13}$$

where $A=\bar{\varrho}+r+r_m$.

The resistances of the thermistor and the metal thermometer in (13) are taken at $\bar{T}=T_0$; $\epsilon=\gamma/\beta_t$ is the ratio of the thermistor and metal thermometer temperature coefficients.

Let us now give an example of computing a differential bridge circuit with copper resistance thermometers ($\beta_t=4.3\cdot10^{-3}$ deg^{-1}): $\bar{\rho}(0)=100$ ohm, the temperature range extends from −50° to +50°C; $r=\bar{\rho}(0)=100$ ohm, $r_m=50$ ohm. The parameters of an MMT-4 thermistor are: $\rho(0)=3250$ ohm, $\gamma=3.2\%$ per deg. From (13) we obtain that $r_{sh}=667$ ohm.

Without a correcting element the sensitivity of the circuit varied by ± 30% in the range of −50° to +50°C. The correcting element brings the variation of sensitivity down to 6.5%, i.e. by a factor of 4.6 (Fig. 4).

If the measured temperature difference ΔT is large, two thermistors in parallel can be connected to the bridge supply circuit, with one at temperature T_1 and the other at T_2. The effective resistance of the compensation circuit will depend on the mean temperature. The same method of connecting thermistors can be used in measuring large temperature differences by means of differential thermocouples.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

INERTIAL PARAMETERS OF RESISTANCE THERMOMETERS AND THERMOCOUPLES

N. A. Yaryshev

Translated from Izmeritel'naya Tekhnika, No. 9,
pp. 25-27, September, 1961

The dynamic properties of thermopiles with uniform volumetric temperature distribution are characterized by a quantity known as the thermal inertia constant:

$$\varepsilon = \frac{\Phi}{\alpha}, \tag{1}$$

where Φ is the heat factor of the thermopile, which is equal to the ratio of its thermal capacity to the area of the external surface; α is the heat transfer coefficient between the medium and the thermopile.

The operation of this simple thermopile in a measuring or controlling circuit is similar to that of an aperiodic (inertial) first order component.

A more complicated construction of temperature meters, the existence of auxiliary elements and protective jackets change the conditions of heat exchange between the sensing element and the ambient medium. A method based on the regular nature of a stable state thermal condition [1, 2, 3] is widely used for evaluating the inertia of complex thermopiles.

It is possible by means of G. M. Kondrat'ev's characteristic curves of inertia to compare the inertia of thermopiles under different operating conditions [2, 4, 5, 6].

Unfortunately the above-mentioned constant, and characteristic thermal inertia curves, are not sufficient to determine fully the dynamic properties of thermopiles and evaluate the errors which arise in measuring nonstationary temperatures.

In order to simplify the analysis in studying the dynamic properties of complex, reinforced thermopiles, they are nominally divided into several elements, each of which is characterized by a definite thermal capacity and thermal resistance. The simplest results are obtained when the actual thermopile is replaced by a model consisting of a central core (stem) and an envelope with lumped thermal capacities separated from each other by thin heat-insulating layers.* This substitution makes the thermopile equivalent in its operation to an aperiodic (inertial) second order component. The inertial properties of the "dual-capacity" thermopile in this instance are determined by parameters m_{en}, β and m_c. The first parameter characterizes the inertia of the envelope and is equal to the ratio of the heat transfer coefficient α between the external surface of the envelope and the medium to the thermal factor Φ_{en}. The parameter β is equal to the ratio of the heat capacity of the core to that of the protective envelope. The third parameter m_c depends on the properties of the core and the heat-insulating layers. It equals the reciprocal of the minimum thermal inertia constant ϵ_∞ of the thermopile.

If these parameters are known it is possible to obtain the most important dynamic characteristics of a thermopile, namely, the thermal inertia characteristic curve, the transmission and transfer functions, amplitude and phase-frequency characteristics, and to establish the mutual relationship between the measured and actual temperatures.

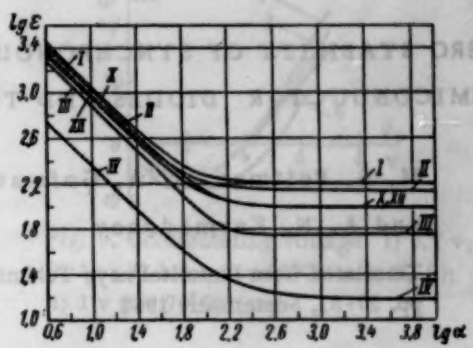
In order to determine the numerical values of the inertial parameters (ϵ_∞, Φ_{en} and β) more than twenty various commercial thermocouples and resistance thermometers were tested. The envelope thermal factors Φ_{en} were found by calculation. Parameter β was determined both by calculation and experimentally by regulated cooling of a completely assembled thermal element in its protective jacket in still air. The data required for calculations were obtained by direct measurements and weighing. The specific heat values of various materials were obtained from reference books for approximately room temperatures.

The value of ϵ_∞ was obtained experimentally by controlled cooling of thermal elements in highly agitated water. For this purpose a 100 liter thermostat with water at $\sim 20°C$ was used. The thermal element temperature variations were registered on a copper-constantan thermocouple with thermal elements 0.1-0.2 mm in diameter. The "hot" junction of the differential thermocouple was placed in the immediate proximity of the thermometer element, and in

*A detailed solution of the problem with respect to commercial thermocouples and resistance thermometers is given in [7, 8].

the case of thermocouples was connected directly to the junction of electrodes. The temperatures were measured and recorded on potentiometer ÉPP-09 with a range of 0-2 mv and a full-scale carriage travelling time of 1 sec. Each thermal element was tested at least 3 times. The value of ϵ_∞ was also determined in still water. It was found that for thermal elements types TKh-XIII, TKhK-VIII, TKh-I, TKh-II, TKhK-XIII, TKhK-140 and ÉTM-XIV the cooling curves in still and stirred water almost coincide. For all the remaining thermal elements the difference between curves taken in still and stirred water was also insignificant. This fact indicates that the values of α obtained in the thermostat are sufficiently large for determining ϵ_∞. The error in measuring ϵ_∞ amounted to 3-4%, and the errors in calculating Φ_{en} did not exceed, on an average, 5-7%; the errors for β were larger, due to the difficulty in determining the dimensions of the internal elements in resistance thermometers without completely dismantling them. It was pointed out in [7] that in evaluating β an error of 20-30% is permissible.

	Types of thermo-elements	Φ_{en}, $\frac{kcal}{m^2 \cdot deg}$	β	ϵ_∞, sec	Notes
I	TKh-II, TKh-VIII, TKh-XIII, TKhK-VIII, TKhK-XIII	2.4 –2.6	0.18–0.20	150–160	For all versions with an external envelope diameter of 21 mm
II	TKh-I	2.0–2.2	0.18–0.20	130–140	
III	TP-II	2.0–2.2	0.02–0.03	55–60	
IV	TP-IV, TP-V	0.40–0.45	0.30–0.45	12–18	
IX	TKh-XV, TKhK-XV	–	–	24–32	According to G. M. Levin's data [6]
X	ÉT-I, ÉT-Ia, ÉT-III, ÉT-IIIa ÉT-VIII, ÉT-VIIIa, ÉT-IX, ÉT-IXa	2.4–2.6	0.14–0.17	90–100	
XI	ÉT-XXI, ÉT-XXII	1.9–2.2	0.01–0.02	6–8	Data for β are tentative
XII	ÉTM-XIV, ÉTM-X	2.0–2.2	0.16–0.18	90–100	
XIII	ÉTM-XI	–	–	55	According to G. M. Levin's data [6]



On the basis of our theoretical and experimental work and the analysis of the work of other authors we have attempted to classify the thermal elements in inertial groups [9]. Information on their nominal dimensions is contained in [10]. Numerical values of the basic inertial parameters for nine groups of thermoelements most widely used in industrial measurements are given in the attached table.

These data may serve as a basis for an approximate evaluation of the inertia of thermoelements under various operation conditions. As an example we provide the thermal inertia characteristic curves $\epsilon = f(\alpha)$ for certain groups of thermoelements (see figure), calculated from equation [8]

$$\varepsilon = \frac{m_c(1+\beta)+m_{en}+\sqrt{[m_c(1+\beta)+m_{en}]^2-4m_c m_{en}}}{2m_c m_{en}}. \quad (2)$$

The basic data for calculations were taken from the table. The calculation results are in good agreement with those of other authors [9].

It will be seen from the figure that for $\log \alpha < 1.8$ ($\alpha < 60$ kcal $\cdot m^{-2} hr^{-1} deg^{-1}$) the temperature distribution in all the thermoelements approaches uniformity and the value of their thermal inertia constant can be found from (1).

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ELECTRICAL MEASUREMENTS

ZERO STABILITY OF SYNCHRONOUS DETECTORS WITH SEMICONDUCTOR DIODES AND TRIODES*

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The accuracy of many measuring, especially automatic, devices, is to a great extent determined by the zero stability of their synchronous detectors (SD).

When the synchronous detectors operate in a vector-measuring condition (a condition registering the quadrature of two vectors), a zero drift component appears which depends on the following factors: the degree of asymmetry of the controlled elements in the voltage-measuring circuit, inequality of the "operating" and "releasing" voltages in the controlled elements, duration of transient processes, and the value of harmonics in the measured and controlling voltages.

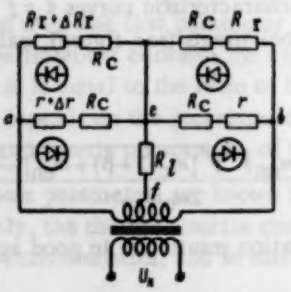

Fig. 1.

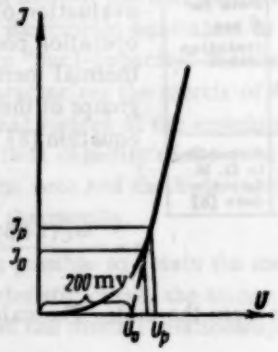

Fig. 2.

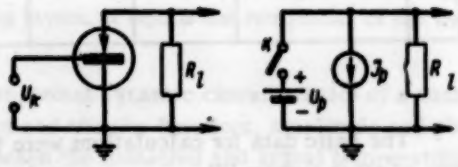

Fig. 3.

Diode synchronous detector circuits. Various ring synchronous detector circuits are most widely used.

In order to reduce zero drift it is recommended [1] that additional resistors be connected in series with the ring detector diodes. In fact this recommendation involves "a reduction of the relative instability by raising the commutating voltage and, hence the limit of the circuit linearity with respect to the measured voltage."

*A paper was read on this problem at the All-Union Session of the Scientific and Technical Society of Radiotechnology and Electrical Communications, in May 1960.

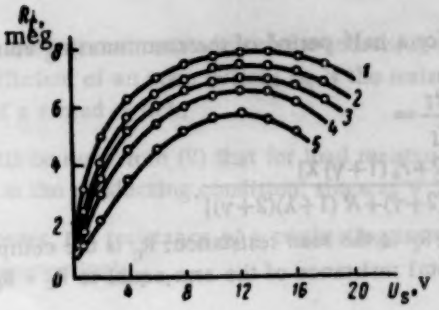

Fig. 4. 1) For 20°C; 2) for 30°C; 3) for 40°C; 4) for 50°C; 5) for 60°C; U_k = + 0.8 v; R_l = 2 kohm.

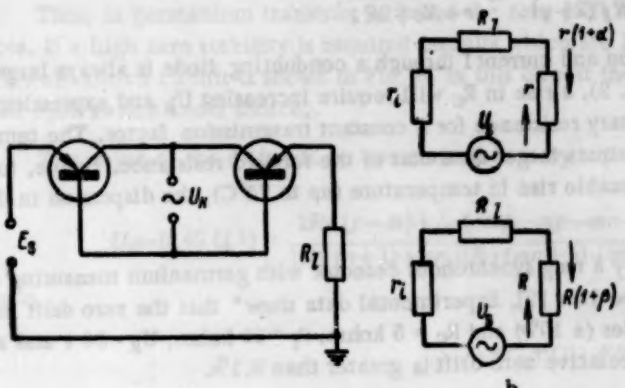

Fig. 5.

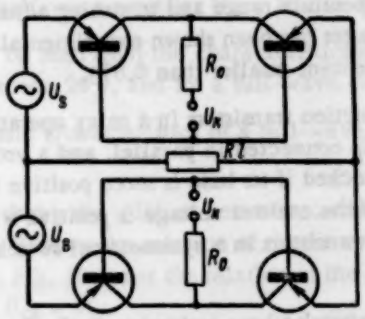

Fig. 6.

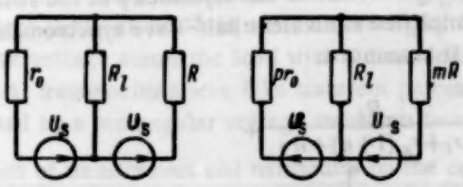

Fig. 7.

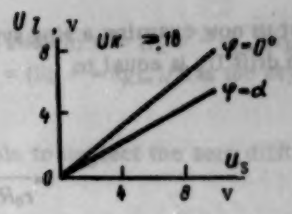

Fig. 8.

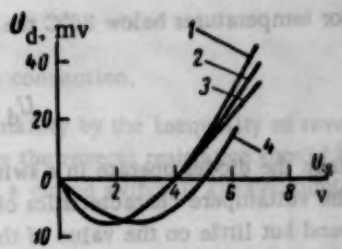

Fig. 9. Commutating voltage: 1) 0.7 v; 2) 1 v; 3) 1.3 v (t = 20°C for 1, 2, 3); 4) 1 v (t = 70°C).

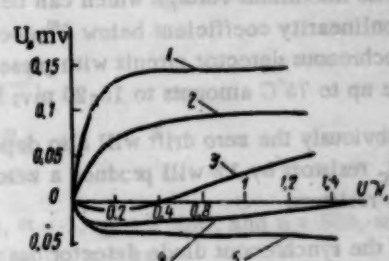

Fig. 10. 1) 60°C; 2) 50°C; 3) 40°C; 4) 30°C; 5) 22°C.

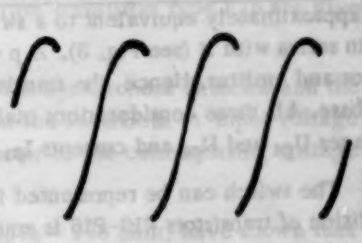

Fig. 11.

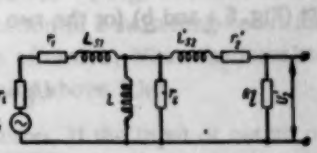

Fig. 12.

Let us now examine a ring synchronous detector circuit for a half-period of the commutating voltage U_k (Fig. 1). The zero drift U_d is equal to

$$U_d = \frac{U_{efxx} R_l}{R_{gt} + R_l} =$$

$$= \frac{0.45\, U_k R_l [\gamma(1+\lambda) R + r_0(1+\gamma)\lambda]}{r_0 R(1+\gamma)(1+\lambda) + R_l [r_0(1+\gamma)(2+\gamma) + R(1+\lambda)(2+\gamma)]},$$

where $r_0 = r + R_C$, $\gamma = \Delta r/(r + R_C)$; $\lambda = \Delta R_r/(R_C + R_r) = \Delta R_r/R$; R_l is the load resistance; R_C is the complementary resistance; R_r is the reversed resistance of the diode; R is the total resistance of the arm, equal to $R_C + R_r$; r is the forward resistance of the diode.

For temperatures below 30°C the dispersion in diode reverse resistances can be neglected. Then we obtain

$$U_d \approx \frac{0.45\, U_k \gamma R_l}{r_0(1+\gamma) + R_l(2+\gamma)} \approx \frac{0.9\, U_k \Delta r R_l}{r + R_C + 2R_l}. \quad (1)$$

Since the diodes operate in a switching condition and current I through a conducting diode is always larger than I_0 (see the voltampere characteristics of diodes in Fig. 2), a rise in R_C will require increasing U_k and expression (1) will depend but little on the value of the complementary resistance for a constant transmission factor. The temperature coefficient of the reverse diode resistance is 3-4 times larger than that of the forward resistance. Hence, for complementary resistances $R_C > 1$ kohm and a considerable rise in temperature (up to 75°C), the dispersion in the diode reverse resistances (R_r) becomes pronounced.

The maximum voltage which can be rectified by a ring synchronous detector with germanium measuring diodes for a nonlinearity coefficient below 2% does not exceed 15 v [2]. Experimental data show* that the zero drift in a ring synchronous detector circuit with preselected diodes (± 10%) and $R_C = 5$ kohm, $R_l = 10$ kohm, $U_k = 30$ v and a temperature up to 75°C amounts to 15-20 mv; hence, the relative zero drift is greater than 0.1%.

Obviously the zero drift will also depend on the instability of the complementary resistors R_C. A change in one of the R_C resistors by 1% will produce a zero drift of approximately $10^{-3}\, U_k$, thus making it necessary to use high stability resistors.

If the synchronous diode detector has to work over a wide temperature range and trimming adjustments are impossible, the error of registering the quadrature of the two input voltages has been shown experimentally to amount to about 1° (the control voltage is sinusoidal with a third harmonic content smaller than 0.5%).

Transistor synchronous detector circuits. It is known [3] that junction transistors in a relay operating condition are approximately equivalent to a switch with the source of current I_p connected in parallel, and a voltage source U_p in series with it (see Fig. 3). A p – n – p transistor can only be blocked if its base is more positive than its collector and emitter. Hence, the transistor cannot block an ac source if the emitter voltage is positive with respect to the base. All these considerations make it necessary to combine two transistors in a symmetrical switch in which voltages U_{p1} and U_{p2} and currents I_{p1} and I_{p2} have opposite signs.

The switch can be represented in the form of a two-terminal network whose resistance in the "conducting" condition of transistors P13-P16 is equal to 3-6 ohm, and in the "blocked" condition to 1-3 meg. The relation between the resistance of a blocked switch and the measured voltage U_s for various temperatures is given in Fig. 4. The zero drift produced by variations in the measured signal voltage is due to the asymmetry of the switch. The value of the zero drift can be determined by superposing two simplified equivalent half-wave synchronous detector circuits (Fig. 5, a and b) for the two polarities of the signal, and it amounts to

$$U_d = \frac{\sqrt{2}}{\pi} U_s \left[\frac{R_l}{r_l + r_k + R_l} - \frac{R_l}{r_l + r_k(1+\alpha) + R_l} + \right.$$
$$\left. + \frac{R_l}{r_l + R_l + R_k} - \frac{R_l}{r_l + R_l + R_k(1+\beta)} \right] \approx \quad (2)$$
$$\approx \frac{\sqrt{2}}{\pi} U_s R_l \left[\frac{\alpha r_k}{(r_l + R_l)^2} + \frac{\beta}{R_k(1+\beta)} \right].$$

*All the numerical values given in this article are the mean of at least 10 characteristics.

where r_i is the internal resistance of the source; r_k is the resistance of an open switch; $\alpha = (r_{k+} - r_{k-})/r_k$ is the asymmetry coefficient of an open switch; R_k is the resistance of a closed switch; $\beta = (R_{k+} - R_{k-})/R$ is the asymmetry coefficient of a closed switch.

It will be seen from (2) that for load resistances $R_l > 1$ kohm it is possible to neglect the zero drift of germanium transistors in the conducting condition, since $r_k < 10$ ohm.

However, the resistance of a conducting transistor is so small only if the condition given below is fulfilled (for a reverse connection):

$$I_{\text{emit.max}} < \frac{\alpha_i}{1-\alpha_i} I_{\text{base}}, \tag{3}$$

where α_i is the current amplification factor of the transistor in the reverse connection.

Thus, in germanium transistor switches the zero drift is determined mainly by the inequality of reverse resistances. If a high zero stability is required circuits which are less affected by the reverse resistance should be used. One such well-known circuit is shown in Fig. 6. In this circuit the resistance of a closed switch is always shunted by that of an open switch and a source.

The value of the drift can be determined here by superposing simplified equivalent circuits shown in Fig. 7:

$$U_d = 0.45\, U_s R_l n \frac{2R_l(p-m)+r_0(nmp-mp-mn-p)}{[R_l(n+1)+nr_0][R_l(mn+p)+mnpr_0]} \approx 0.45\, U_s R_l r_i \frac{2R_l(p-m)+mn\alpha r_\kappa}{(R_l+r_i)^2 mR_\kappa}, \tag{4}$$

where

$$r_0 = r_\kappa + r_i; \quad p = \frac{r_\kappa(1+\alpha)+r_i}{r_\kappa+r_i};$$

$$m = \frac{R_\kappa(1+\beta)}{R_\kappa} = 1+\beta; \qquad n = \frac{R_\kappa}{r_0}.$$

If we assume that $U_s = 10$ v, $r_i = 1$ kohm, $R_l = 10$ kohm, $\beta = 1$ (m = 2), $\alpha = 1$, $r_k = 5$ ohm, and n = 500, we shall obtain for a half-wave rectifier $U_d \approx 50$ mv, and for a full-wave rectifier $U_d \approx 6$ mv.

It will be seen from the characteristics of Fig. 4 that for a half-wave synchronous detector the value of U_c should not exceed 20 v, and for a full-wave detector 10 v.

The basic characteristics of a full-wave synchronous detector with junction transistors type P15 are given in Figs. 8-10.

Fig. 8 shows the relation between the rectified voltage at the output of the synchronous detector and the input voltage. Fig. 9 shows the relation of the zero drift of a synchronous detector to the variations in input voltage and temperature. Fig. 10 shows the relation of the zero drift of a synchronous detector to the commutating voltage and temperature ($U_s = 0$).

Tests of more than 10 synchronous detectors ($r_i = 500$ ohm, $R_l = 10$ kohm, $R_0 = 200$ ohm) have shown that the relative zero drift due to variations in the commutating voltage of ± 30% (1 ± 0.3 v) in the temperature range of 10-75°C did not exceed 0.01%, and the error in registering the quadrature of vectors in the same temperature interval for variations in U_s of ±50% (4 ± 2 v) and in U_k of ± 30% (1 ± 0.3 v) amounted to 0.3°*. Fig. 11 shows an oscillogram of the voltage across the load with a clear indication of the transistor operation in a switching condition for $f = 5$ kc. At frequencies above 5 kc transient processes in the transistors become effective. When the transistors are commutated by a rectangular voltage transients become appreciable at frequencies above 1 kc.

Effect of transformers and harmonics on the zero drift in synchronous detectors. If the input or output of a synchronous detector has to be grounded, transformers are usually employed. Due to the considerable nonlinearity of the circuit the phase shift introduced by the transformer varies with the input voltage and is equal to

$$\arctan = \frac{R_l r_i - \omega L (L_{S1} - L'_{S2})}{\omega L (R_l + r_i)}. \tag{5}$$

*A random error is under consideration, i.e. the relative zero drift in a vector-measuring condition for voltage and temperature variations in the abovementioned range. The commutating voltage is sinusoidal and its third harmonic amounts to less than 0.5%.

(The winding resistances r_1 and r'_2, and the core losses r_c are neglected. See the equivalent transformer circuit in Fig. 12.)

Normally the transformer is connected to the output of an electronic amplifier. In such a case the most effective way of raising the synchronous detector stability consists in applying a negative feedback which includes the transformer. This also reduces the phase instability of the channel and the output resistance r_i, which according to (4) leads to a reduction in the zero drift, while at the same time the linearity of the channel is raised.

Fig. 13 shows the relation of the zero drift in synchronous detectors to the voltage at the input of the transformer with feedback (curve II, $K_\beta = 9$) and without it (curve I).

The error in registering the quadrature of two vectors due to harmonics in the measured voltage is determined by odd harmonics (in practice by the third harmonic):

$$\gamma = \arcsin \frac{n \sin 3\beta}{3}, \tag{6}$$

where n is the voltage ratio of the third harmonic to the fundamental; β is the phase difference between the third harmonic and the fundamental.

The error due to harmonics in the commutating voltage is determined by the displacement of the half-period commutation midpoints and is equal to

$$\gamma = \frac{m^2 \sin 4\alpha - n \sin 3\beta - 3n^2 \cos 3\beta \sin 3\beta}{(1+3n\cos 3\beta)^2 - 4m^2 \cos^2 2\alpha} \approx \approx \frac{m^2 \sin 4\alpha - n \sin 3\beta}{1+6n\cos 3\beta}, \tag{7}$$

where m is the voltage ratio of the second harmonic to the fundamental; α is the phase difference between the second harmonic and the fundamental.

Error (7) will be systematic if m, n, α and β are constant. Hence, it is desirable to have a stable commutating voltage with a low harmonic content, and it is not advisable to have reactive components (phase shifter) in the commutation channel, since this leads to variations in α and β.

Conclusions. In a general case for any synchronous detector circuit the zero drift due to an asymmetry in the controlled element resistance is equal to

$$U_0 = K_n \alpha r + K_0 \beta \frac{1}{R_r}, \tag{8}$$

where K_n and K_0 are coefficients depending on the design of the circuit and its parameters.

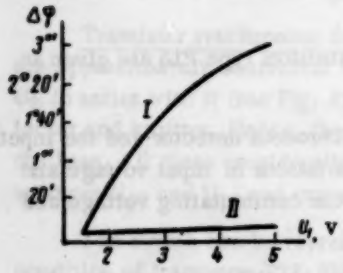

Fig. 13.

It will be seen from (8) that in designing synchronous detector circuits it is advisable to select controlled elements whose resistance is at a maximum in the blocked position, and at a minimum in the conducting position. These conditions are best fulfilled by transistors in a reversed connection operating under relay conditions. Hence, wherever the frequency range requirements are suitable, diodes should be replaced by transistors.

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DESIGN OF PHOTOCOMPENSATED INSTRUMENTS

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and A. N. Tkachenko

Translated from Izmeritel'naya Tekhnika, No. 9,
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The basic considerations for designing photocompensated amplifiers and stabilizers are given in [1, 2, 3]. The basic parameters in these calculations consist of the design parameters of the galvanometer and the amplifying circuit (moment of inertia and interlinkage of the moving part, specific restoring moment of the elastic elements, conversion factor of the circuit, etc.).

Such an approach is only convenient when it is possible to change these parameters. Normally this can only be achieved in an instrument-making plant.

At present the "Vibrator" Plant is producing a series of photoelectric amplifiers F117 which combine in a single unit the galvanometer, photovaristors and the optical system. The instruments are manufactured in diffferent versions, thus making them suitable for various practical applications. In view of the availability of ready-made amplifiers F117 the problem arises of designing photocompensated amplifiers on the basis of operational parameters which can vary for different samples and operation conditions, but are easily determined experimentally. These parameters consist of the current amplification factor, internal resistance of the galvanometer, the critical impedance, and the free oscillation period of the moving part.

The photocompensated amplifier consists of a system with an over-all negative feedback due to which the galvanometer's moving part is subjected to an electrical restoring moment which is several times larger than the counteracting moment of the galvanometer. In a circuit without inertia the dynamic properties of the amplifier are determined by the free oscillation period T and the degree of damping β, which are considerably smaller than the oscillation period and degree of damping of the amplifier galvanometer away from the circuit [1]. R. R. Kharchenko has shown that the values of T and β can be expressed in terms of the operational parameters of a photoelectric amplifier [4]:

$$\beta = \frac{\beta_0}{\sqrt{1+K_a\eta}}; \quad (1)$$

$$T = \frac{T_0}{\sqrt{1+K_a\eta}}, \quad (2)$$

where T_0 is the galvanometer's period of free oscillations outside the compensation circuit; β_0 is the galvanometer's degree of damping in the compensator circuit but with a disconnected feedback circuit; K_a is the current amplification factor of the photoelectric amplifier without a feedback, and equal to the product of all the stage amplification factors of the system; η is the feedback factor equal to the ratio of the current branched off to the galvanometer from the output circuit to the total output current.

The figure shows the two basic circuits of photocompensated amplifiers, namely those with voltage a and current b compensators.

According to the definition of an amplification factor we have

$$K_a = \frac{I}{i} = \frac{I\psi K_c}{iW_m} = \frac{\psi K_c}{W_m}. \quad (3)$$

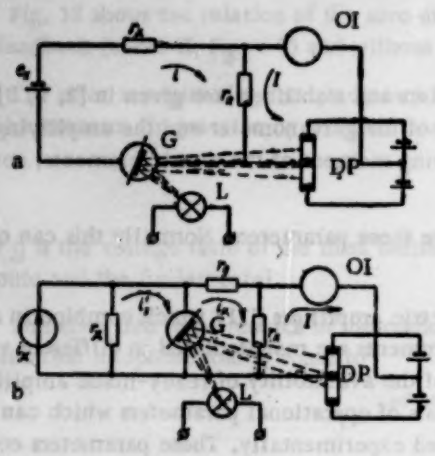
Adopting the notation shown on the drawing we have for the voltage-compensated circuit:

$$\eta_e = \frac{r_\kappa}{r_g + r_x + r_\kappa} \quad (4)$$

and for the current-compensated circuit:

$$\eta_i = \frac{r_\kappa}{r_\kappa + r_g + r_d + \frac{r}{r_x} g\,(r_d + r_\kappa)}, \tag{5}$$

where r_g is the resistance of the galvanometer coil; ψ is the flux linkage of the galvanometer; K_C is the conversion factor equal to the ratio of the amplifier's output current increment to the moving coil rotation angle which produced it; W_m is the specific restoring torque of the galvanometer.



G is the galvanometer; DP is the differential photovaristor; OI is the output instrument; L is the photoamplifier's illuminating lamp.

In the most prevalent case, when the galvanometer damping is provided only by its moving coil, we have

$$\beta = \frac{r_{cr}}{r_g + r_l}, \tag{6}$$

where r_{cr} is the critical impedance of the galvanometer (can be either determined experimentally or calculated); r_l is the resistance of the galvanometer load circuit.

If the galvanometer is fitted with a frame, liquid damping, etc., the degree of damping is equal to the sum of the damping in the winding and the damping devices.

It should be stressed that the dynamic properties of the photocompensated amplifier do not depend on the specific restoring moment W_m of the stressed suspensions. This is due to the fact that in practice $\eta K_a \gg 1$ and that T_0, β_0 and $\sqrt{K_a \eta}$ are proportional to $1/\sqrt{W_m}$.

Expressions (1) and (2) hold if the inertia of all the photoamplifier circuit elements is considerably smaller than that of the galvanometer. If this condition is not met, the order of the characteristic photocompensated equation is raised. Moreover, the dynamic characteristics of the system deteriorate and there arises the possibility of self-oscillations. The stability of the photocompensated amplifier is determined, its transient processes analyzed, and its dynamic characteristics improved by methods normally employed in automatic control systems. The condition of balance in systems represented by third-order characteristic equations consists of $\beta > 0{,}5$ [3].

On the basis of the well-known relationships for systems with an over-all negative feedback it can easily be shown that the relation of the output current to the measured variable is determined by the following formulas:

a) for a voltage compensator

$$u_x = I r_\kappa \left(1 + \frac{1}{K_a \eta_e}\right); \tag{7}$$

b) for a current compensator

$$i_x = I \frac{r_\kappa}{r_\kappa + r_d}\left(1 + \frac{1}{K_a \eta_i}\right), \tag{8}$$

where $1/K_a \eta_e$; i is the system's static error, which is related to the compensation error γ_0 [1] by the expression

$$\gamma_0 = \frac{1}{1 + K_a \eta_{e;i}}. \tag{9}$$

In order to avoid ambiguity in evaluating the compensation error it is necessary to distinguish between two possible methods of its standardization.

If the measured variables consist of emf e_x and current i_x, which is flowing through the circuit before an amplifier is connected to it, the compensation error of the amplifiers is determined from (9).

If, on the other hand, photocompensated amplifiers are considered as normal electrical measuring instruments which consume a certain power from the measured circuit, their error should be determined for a given current or

voltage, in the same way as it is done with ordinary ammeters or voltmeters. Relations for this case can be obtained from equation (9) if in calculating η it is assumed that $r_x = 0$ for a voltage compensator and $r_x = \infty$ for a current compensator. The feedback coefficients will then be equal to

$$\eta'_e = \frac{r_\kappa}{r_g + r_\kappa}; \quad \eta'_i = \frac{r_\kappa}{r_g + r_g + r_\kappa}. \tag{10}$$

In the cases when the compensation error is too high it can be reduced by one of the methods described in [1].

Photocompensated amplifiers consume very little energy from the measured circuit. The consumption of a photocompensated amplifier is determined by its input resistances.

For a voltage compensator the input resistance is

$$r_{in\,e} = \frac{e_x}{i} - r_x = r_g + r_\kappa (1 + K_a). \tag{11}$$

For a current compensator it is

$$r_{in\,i} = \frac{i_g r_g}{i'_x} = \frac{r_g}{K_a \dfrac{r_\kappa}{r_\kappa + r_d}\left(1 + \dfrac{1}{K_a \eta_i}\right)}, \tag{12}$$

where $i_g = i'_x - i_k$ is the current flowing through the galvanometer.

It should be noted that (11) and (12) only hold for a strictly defined zero position of the galvanometer moving coil.

Instrument type	Parameters				
	Current amplification factor K_a, not less than	Moment of inertia of the galvanometer's moving part, g·cm²	Flux linkage, maxwell-turns	Specific counteracting torque, $\frac{\text{d·cm}}{\text{rad}}$	Galvanometer resistance r_g, ohm
F 117/1, F117/6	$12 \cdot 10^3$	0.12	$0.5 \cdot 10^6$	0.85	10
F 117/2, F117/7	$24 \cdot 10^3$	0.14	$1.3 \cdot 10^6$	1.15	50
F 117/3, F117/8	$40 \cdot 10^3$	0.13	$2.2 \cdot 10^6$	1.15	140
F 117/4, F117/9	$80 \cdot 10^3$	0.12	$4.3 \cdot 10^6$	1.15	620
F 117/5, F117/10	$340 \cdot 10^3$	0.09	$8.6 \cdot 10^6$	1.55	5100
F 117/11*	$36 \cdot 10^3$	0.12	$3.8 \cdot 10^6$	2.1	950
F 117/12*	$22 \cdot 10^3$	0.12	$1.3 \cdot 10^6$	1.15	80

*The moving coil has a frame which provides the galvanometer with the external circuit disconnected, with a degree of damping $\beta = 25$ for type F117/11 and with $\beta = 40$ for type F117/12 amplifier.

In conclusion we shall provide the parameters of photoelectric amplifiers type F117 and give an example of the use of the described method for computing photocompensated amplifiers.

Amplifier F117 is made in 12 versions, which differ by their galvanometer parameters and the smoothness of their correctors. The basic amplifier data are given in the table.

Amplifier gain is specified for an illuminator lamp heater voltage of 3.5 v, a voltage across the differential photovaristor of 2×50 v, and a load resistance of 3000 ohm. Under these conditions the linear part of the amplifier output current amounts to at least 1.5 ma on either side of the zero and the saturation current is at least 2.5 ma. The noise emf at the output amounts to 1-2 mv.

For the above supplies the output resistance of the amplifier is 5-10 kohm. The amplifier output current drift does not exceed 50 μa per hour and its internal thermal emf is less than $5 \cdot 10^{-8}$ v (when the amplifier is connected to the compensation circuit its drift is considerably reduced owing to the negative feedback).

The illuminating lamp heater voltage and the photovaristor supply voltage can be changed, but the photovaristor dissipation power must not exceed 0.5 - 0.7 w.

The time constant of differential photovaristors amounts to about 0.01 sec.

In the versions F117/1, 2, 3, 4, 5 and 12 a highly-smooth corrector is used (one turn of the corrector's axis provides a variation in the output current of 0.15 ma). Amplifiers F117/6, 7, 8, 9, and 10 have a corrector which is 7 times coarser. Version F117/11 has no corrector at all.

As an example let us examine the possible parameters for a voltage compensator with a measuring limit of $e_x = 15$ μv and a source resistance of $r_x \leq 10$ ohm.

We choose photoamplifier F117/1 since the resistance of its galvanometer matches that of the source. Let us assume nominal supplies for the photovaristor and the illuminating lamp.

For the selection of an output instrument let us evaluate the noise level at the compensator output, considering tentatively that the resistance of the output instrument is r_{oi} = 3 kohm, and that of the photovaristor is r_{pv} = kohm.

$$I_n = \frac{e_n}{r_{pv} + r_{oi}} = \frac{2 \cdot 10^{-3}}{10 \cdot 10^3} = 0.2\ \mu a,$$

where $e_n = 2 \cdot 10^{-3}$ v is the noise emf at the output.

Hence, assuming that the output noise level must not exceed 0.3% of the output instrument's full-scale deflection, we select a 75 μa instrument.

Neglecting the error due to insufficient compensation we find the compensation resistance

$$r_\kappa = \frac{e_x}{I} = \frac{15 \cdot 10^{-6}}{75 \cdot 10^{-6}} = 0.2\ \text{ohm}.$$

From (4) the feedback coefficient will be

$$\eta_e = \frac{0.2}{0.2 + 10 + 10} \approx 10^{-2}$$

The compensation error and dynamic parameters of the instrument are now obtained immediately:

$$\gamma_0 = \frac{1}{1 + \eta_e K_a} \approx \frac{1}{10^{-2} \cdot 1.2 \cdot 10^4} =$$

$$= 8 \cdot 10^{-3} \quad \text{or} \quad \gamma_0 = 0.8\%.$$

$$T = \frac{2.5}{\sqrt{1 + 10^{-2} \cdot 1.2 \cdot 10^4}} \approx 0.25\ \text{sec}.$$

$$\beta = \frac{400}{(0.2 + 10 + 10)\sqrt{1 + 10^{-2} \cdot 1.2 \cdot 10^4}} \approx 2.$$

Since the photocompensated amplifier's degree of damping is $\beta > 0.5$, the amplifier is stable.

It follows from [3] that for the values of T and β thus obtained the damping time of the amplifier can be determined without taking into consideration the inertia of the photovaristor:

$$t_a \approx 1.2\beta T = 0.6\ \text{sec}.$$

Since t_a is small, the total damping time of the device will be determined by the output instrument, which normally has a decay time of 2-4 sec.

The input resistance of the instrument according to (1) will be

$$r_{in} = 10 + 0.2(1 + 1.2 \cdot 10^4) \approx 2400\ \text{ohm}.$$

The above computation demonstrates the excellent parameters which can be obtained by means of photoelectric amplifiers. The relationships provided in this article may render considerable assistance in designing compensators.

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DIRECT CURRENT BOLOMETRIC BRIDGE FOR MEASURING UHF POWER

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Peculiarities of film bolometers and requirements for their measurement circuits. A film bolometer used as an element for receiving UHF power has characteristics which differ from those of a thermistor and determine its properties as a power meter as well as the requirements and the design of the measuring circuit in which it is used.

Its most important peculiarities consist of its relatively small power sensitivity $S = dR/dP$ and its relatively large instability.

The power sensitivity of film bolometers is 2-3 orders lower than that of hf thermistors. In relatively high-power bolometers (of the order of 1 w) it amounts to 0.02-0.04 ohm/mw and in low-power bolometers (units and tens of milliwatts) the sensitivity is higher and attains values of the order of 0.08-0.15 ohm/mw.

Owing to the low sensitivity of film bolometers it is:

a) necessary to raise considerably the sensitivity of indicating devices, or raise the minimum measuring limits of the device; b) impossible to maintain the required value of the bolometer's operating resistance over a wide range by varying the heating power, as is done in thermistor power meters, thus making it necessary to provide in addition to the bolometer current adjustment, also a facility for preliminary balancing of the bridge by means of special adjustable resistors; c) difficult to make the substitution of the measured power automatic in the bolometric bridge, in view of the required high sensitivity and the relatively large output power of the controlling amplifier over wide measuring ranges.

The maximum permissible power of film bolometers varies considerably with the frequency range for which the bolometer is designed. Thus, it becomes impossible to cover the whole power range of bolometric measurements by means of one instrument with a single maximum heating power, owing to the excessive stability required in the supply current. Moreover, since the supply power of a bolometric bridge must be considerable in order to ensure maximum measurement ranges, the measuring circuit should be provided with optimum parameters for reducing its power consumption.

The relatively large instability with time of a film bolometer leads to an instability in the bolometric meter readings which is considerably larger than that of a thermistor meter. For instance, in a reference thermistor power meter type MTO-1 the guaranteed instability does not exceed 1 μw per 30 sec [1], and in fact it is considerably smaller, whereas the instability of low-power bolometers is of the order of 5 μw per 30 sec.

This instability consists of two components, one of which is due to the variations of the bolometer resistance with time, and the second to the effect of ambient temperature variations.

If it is assumed that the variations of a film bolometer resistance due to structural changes may attain 1% per month, the error in measuring power due to corresponding changes in the bolometer resistance during measurement (for half a minute), $\Delta P = \Delta R/S$, with a bolometer resistance of 600 ohm and a sensitivity of 0.08 ohm/mw, will amount to 0.8 μw.

A film bolometer has a considerably larger temperature instability than an UHF thermistor.

In order to evaluate it let us make a tentative calculation of this instability for both elements of the same operating resistance of 400 ohm and a change in the ambient temperature of 0.01°C. The error due to temperature variations can easily be found from the relationship $\Delta P/\Delta t = \alpha R/S$, where α and R are the temperature coefficient and the operating resistance of the thermistor or the bolometer respectively. The computed data are given in Table 1.

It will be seen from the table that the temperature instability of a bolometer is approximately 50 times greater than that of a thermistor, which must be taken into account in UHF bolometric power measurements. This circumstance constitutes a most important limitation which makes it impossible to lower the measuring limit of bolometric meters to the values obtained with thermistor meters.

Schematic of a bolometric UHF power meter. The schematic of a direct-reading bolometric UHF power meter designed on the basis of the aforementioned peculiarities of film bolometers [2] is shown in the attached figure. The meter is designed on the basis of a double bridge consisting of an external supply bridge and an internal measuring bridge. Moreover it includes a stable supply source 1 with a photocompensated direct current stabilizer, an indicating instrument consisting of a pointer ferrodynamic wattmeter, a null-indicator 2 with a photocompensated direct voltage amplifier, and a compensated current source 3.

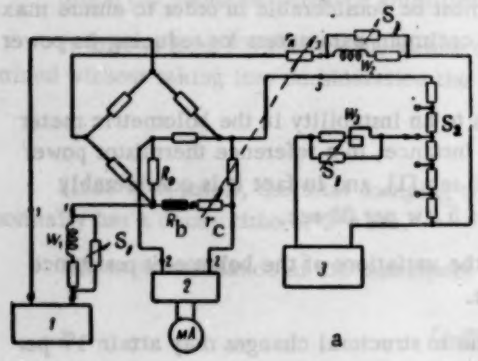
Bolometer R_b together with its complementary resistor r_c is connected into the arm of the internal bridge. The resistance of the fixed comparison arm is equal to the maximum possible operating resistance of the bolometer. One of the stationary windings W_1 of the registering instrument is connected to the bridge supply circuit, and the other stationary winding W_2 and moving coil W_3 are connected to the compensation circuit.

TABLE 1

Sensitive element type	Working resistance R, ohm	Temperature coefficient α, 1/deg	Sensitivity S, ohm/w	Instability ΔP/Δt, μw/0.01°C
Thermistor	400	$3 \cdot 10^{-2}$	$1 \cdot 10^{5}$	1
Metallic film bolometer	400	$1 \cdot 10^{-3}$	$0.8 \cdot 10^{2}$	50

Before measuring the UHF power the bridge is balanced, first by means of the complementary resistor r_c and then with the bolometer heating current by adjusting the photocompensated stabilizer output voltage.

The UHF power fed to the bolometer is balanced out by reducing the bolometer heating current with the compensation current which is supplied in the opposite direction. The compensating current which is obtained from a ferroresonant stabilizer and rectifier 3 (which has a potential divider at its output) is manually adjusted for the bridge balance as shown by the null indicator. The measured power is read off the wattmeter scale.



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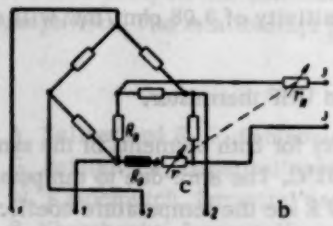

b

Taking into consideration the relation between the parameters of the circuit shown in Fig. a, the torque acting on the wattmeter's moving part, which is located in the opposing fields of the stationary windings, is equal to

$$M = cWW_3k_2k_3A\left(1+\frac{R_1}{R_2}\right)^2 \frac{P_{ms}\sum R}{RR_b} \qquad (1)$$

providing

$$W = W_1 = W_2 \text{ and } k_1\left(1+\frac{R_0+r}{2R_1}\right) = 2k_2\left(1+\frac{R_1}{R_2}\right), \qquad (2)$$

where W_1, W_2 and W_3 represent the number of windings of the two stationary and one moving coil of the wattmeter respectively; k_1, k_2 and k_3 are the shunt coefficients of the wattmeter windings; R_1 and R_2 are the resistances of the bridge circuit arms; R_b is the working resistance of the bolometer; P_{ms} is the UHF power; R is the part of the universal shunt resistance through which the compensation current is fed to the circuit; ΣR is the total resistance of the compensation circuit.

It will be seen from (1) that in switching the measuring ranges and bands for setting a given bolometer resistance it is necessary to keep constant the following expression

$$\left(1+\frac{R_1}{R_2}\right)^2 k_2 k_3 \frac{P_{ms}\sum R}{RR_b} = \text{const.} \tag{3}$$

In order to change the measuring limits within a band it is necessary to adjust the shunt resistance R so as to keep P_{ms}/R = const. For changing measuring bands, the shunting coefficients k_2 and k_3 should be adjusted. It will be seen from (2) that k_2 and k_1 must be changed simultaneously. The setting of the required bolometer resistance R_b is achieved by adjusting the complementary resistor $r_C = R_0 - R_b$. At the same time it is necessary to change the compensating circuit resistance so as to maintain $\Sigma R/R$ = const.

Switch S_1 is used in the instrument for changing bands by varying the shunting coefficient of the stationary and the moving coils, and the universal shunt S_2, which serves to connect the instrument's moving coil W_3 to the compensation circuit, is used for changing the measuring ranges. In order to use the same scale for various bolometer resistances the complementary resistor r_k in the compensating circuit is changed simultaneously with the complementary resistor r_C.

Taking into consideration the relations between the parameters of the circuit shown in Fig. b, we obtain an expression for the wattmeter torque:

$$M = cWW_3k_2k_3A\frac{P_{ms}\sum R}{RR_b} \tag{4}$$

providing

$$W = W_1 = W_2 \text{ and } k_1\left(1+\frac{R_2+r}{2R_1}\right) = 2k_2. \tag{5}$$

The switching of measuring limits and the setting of a given bolometer resistance are done in the same manner as for the circuit in Fig. a.

Instrument circuit a (see figure) consists of a symmetrical supply bridge and a null-indicator connected to the output of an internal bridge. This circuit is used for small measuring ranges with waveguide bolometric heads where a large sensitivity of the measuring bridge is required. Circuit b (see figure) consists of an asymmetrical supply bridge with the compensation circuit included in the diagonal of the internal bridge in order to reduce the consumption of the supply source and the compensation current source over wide measuring ranges used with coaxial bolometric heads.

For setting the bolometer heating current the microammeter is switched from the null-indicator at the photocompensated amplifier output to the heating circuit. In order to preserve the same bridge imbalance for various measuring ranges, the amplifier sensitivity is changed simultaneously with the measuring ranges.

Technical characteristics of the instrument. The power meter made according to the schematic shown above comprises a reference bolometric bridge MBO-1, a source of supplies, a dc voltage stabilizer U1136 of the "Vibrator" Plant, and a set of waveguide and coaxial heads.

The power meter has the following technical characteristics:

A measuring range from 100 μw to 1 w, to suit the permissible power in the bolometer (Table 2).

The range of bolometer operating resistances with which the bridge can work extends from 180 to 640 ohm.

The basic error of the MBO-1 bridge does not exceed for each of the basic scales ± 1.5%, for the first additional scale in each band ± 4%, for the second additional scale in each band ± 2.5%.

The total error of the meter including bolometric heads with a certified efficiency used in a matched line over the whole frequency range of the bolometric heads does not exceed 6% on all the basic measuring scales, and 10% on the additional scales.

TABLE 2

Band	Measuring scale, mw		Heating power, mw
	basic	additional	
I	1–3–10	0.1–0.3	15
II	10–30–100	1–3	150
III	100–300–1000	10–30	1250

The instability of the power meter reading for half a minute does not exceed:

5 μw on the scales of band I (0.5% of the smallest main full-scale deflection);

20 μw on the scales of band II (0.2% of the smallest main full-scale deflection);

200 μw on the scales of band III (0.2% of the smallest full-scale deflection).

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MISMATCHING ERRORS IN MEASURING AND COMPARING OSCILLATOR OUTPUT VOLTAGES

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In checking oscillators which are designed to work in matched lines it is necessary to measure the so-called nominal output voltage, i.e. the voltage across a nominal resistance equal to the characteristic impedance of the line. If the input impedance of the voltage meter differs from the nominal a mismatching error arises.

The voltage across the meter (load) developed by the oscillator is equal to

$$U_L = U_{on}\, e^{-j\beta d}\, \frac{1+\bar{\Gamma}_L}{1-\bar{\Gamma}_0 \bar{\Gamma}_L e^{-2j\beta d}}, \qquad (1)$$

where Γ_L is the reflection factor of the load; Γ_0 is the reflection factor of the oscillator; U_{on} is the initial voltage wave across the oscillator or the nominal output voltage; $\beta = 2\pi/\lambda$ is the propagation constant; d is the length of the line between the oscillator and the load.

The ratio of the voltage meter reading to the nominal voltage is

$$\left|\frac{U_L}{U_{on}}\right| = \sqrt{\frac{1+2\Gamma_L \cos\varphi_L + \Gamma_L^2}{1+2\Gamma_L\Gamma_0\cos\varphi_{L0} + (\Gamma_L\Gamma_0)^2}}, \qquad (2)$$

where φ_L is the phase angle of the load; φ_{L0} is the difference in the oscillator and load phase angles measured at the same point.

For small Γ_L and Γ_0 we have

$$\left|\frac{U_L}{U_{on}}\right| \approx 1+\Gamma_L \cos\varphi_L - \Gamma_L\Gamma_0 \cos\varphi_{L0}. \tag{3}$$

If Γ_0 is smaller than Γ_L and both are of the same order, we obtain

$$\left|\frac{U_L}{U_{on}}\right| \approx 1+\Gamma_L \cos\varphi_L. \tag{4}$$

The matching error is equal to

$$\Theta \approx \Gamma_L \cos\varphi_L. \tag{5}$$

In the most unfavorable case $\Theta \approx \pm \Gamma_L$.

In practical checking and testing it is often necessary to compare the nominal voltages of two oscillators, for instance, of a reference and tested oscillator. Such comparisons are made by alternately connecting the two generators to a voltage meter (comparator). If the oscillator impedances and the comparator input impedance differ from the nominal value (the line characteristic impedance) mismatching errors arise. Below we examine mismatching errors for certain common instances.

I. The nominal voltage of the reference oscillator is known.

The ratio of the voltage moduli at the outputs of the two generators, which are alternately connected to the same load, is equal to

$$\left|\frac{U_{L2}}{U_{L1}}\right| = \frac{U_{on2}\,|(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1})|}{U_{on1}\,|(1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_2})|}. \tag{6}$$

In comparing the voltages the same reading on the comparator is obtained:

$$\left|\frac{U_{L2}}{U_{L1}}\right| = 1.$$

The ratio of the nominal output voltages will then be

$$\frac{U_{on2}}{U_{on1}} = \left|\frac{1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_2}}{1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1}}\right|. \tag{7}$$

If the values of Γ_L and Γ_0 are measured at the same point ($d_2 = d_1 = 0$) or with the same connecting line between the oscillator and the load ($d_2 = d_1$), then

$$\frac{U_{on2}}{U_{on1}} = \left|\frac{1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L}{1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L}\right|. \tag{8}$$

For the least favorable phase relation the value of relation (8) is within the limits

$$\frac{U_{on2}}{U_{on1}} = \frac{1\pm\Gamma_{0_2}\Gamma_L}{1\mp\Gamma_{0_1}\Gamma_L} \approx 1\pm\Gamma_L(\Gamma_{0_1}+\Gamma_{0_2}).$$

For instance, $\Gamma_L = \Gamma_{0_1} = \Gamma_{0_2} = 0.1$; (9)

$$\frac{U_{on2}}{U_{on1}} = 1\pm 0.02.$$

It will be seen that nominal values of the oscillator voltages can be compared with a small error (of the order of the square of the reflection factor) even for considerable reflections from the comparator input, despite the fact that the absolute value of the voltage across the resistance may, according to (5), differ considerably from the nominal.

II. The emf U_θ of the oscillator is known. Then

$$U_{on}=\bar{U}_0\,\frac{Z_0}{\bar{Z}_g+Z_0}=\bar{U}_0\left(\frac{1-\bar{\Gamma}_0}{2}\right). \tag{10}$$

Here the phase of U_{on} was assumed to be the initial phase, hence the emf U_0 will be a complex quantity. In comparing two oscillators by their emfs we can insert (10) into (6) and obtain the voltage ratios at the comparator

$$\left|\frac{U_{L2}}{U_{L1}}\right|=\left|\frac{U_{02}}{U_{01}}\right|\left|\frac{(1-\bar{\Gamma}_{0_2})(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1})}{(1-\bar{\Gamma}_{0_1})(1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_2})}\right|. \tag{11}$$

When the comparator readings are the same we have

$$\left|\frac{U_{L2}}{U_{L1}}\right|=1;$$
$$\left|\frac{U_{02}}{U_{01}}\right|=\left|\frac{(1-\bar{\Gamma}_{0_1})(1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_1})}{(1-\bar{\Gamma}_{0_2})(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_2})}\right|. \tag{12}$$

For the least favorable relation of phases we obtain

$$\left|\frac{U_{02}}{U_{01}}\right|=\frac{(1\pm\Gamma_{0_1})(1\pm\Gamma_{0_2}\Gamma_L)}{(1\mp\Gamma_{0_2})(1\mp\Gamma_{0_1}\Gamma_L)}\approx$$
$$\approx 1\pm(\Gamma_{0_1}+\Gamma_{0_2}+\Gamma_{0_2}\Gamma_L+\Gamma_{0_1}\Gamma_L).$$
For instance, $\Gamma_{0_1}=\Gamma_{0_2}=\Gamma_L=0.1$; (13)
$$\frac{U_{02}}{U_{01}}=1\pm(0.1+0.1+0.01+0.01)=1\pm 0.22.$$

It will be seen from (13) that the maximum error in comparison measurements is produced by the reflection factors of the oscillators.

III. The reference oscillator's emf U_{01} is known, and the tested oscillator's voltage U_{on2} has to be measured across the matched load.

Let us insert (10) into (1):

$$\bar{U}_{L_1}=\bar{U}_{01}\left(\frac{1-\bar{\Gamma}_{0_2}}{2}\right)\frac{(1+\bar{\Gamma}_L)\,e^{-j\beta d_1}}{1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1}}. \tag{14}$$

By inserting (14) into (6) and equating to unity we have

$$\left|\frac{U_{L2}}{U_{L1}}\right|=\left|\frac{U_{on2}\cdot 2\cdot(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1})}{U_{01}(1-\bar{\Gamma}_{0_1})(1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_2})}\right|=1;$$
$$2\left|\frac{U_{on2}}{U_{01}}\right|=\left|(1-\bar{\Gamma}_{0_1})\frac{(1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_1})}{(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_2})}\right|. \tag{15}$$

If Γ_{0_1} is small, i.e. if the oscillator impedance with a known emf U_{01} approaches the nominal impedance of the line, we obtain for the least favorable combination of phases

$$2\,\frac{U_{on2}}{U_{01}}=\frac{(1\pm\Gamma_{0_1})(1\pm\Gamma_{0_2}\Gamma_L)}{(1\mp\Gamma_{0_1}\Gamma_L)}\approx$$
$$\approx 1\pm(\Gamma_{0_1}+\Gamma_{0_2}\Gamma_L+\Gamma_{0_1}\Gamma_L).$$
For instance, $\Gamma_{0_1}=\Gamma_{0_2}=\Gamma_L=0.1$; (16)
$$2\,\frac{U_{on2}}{U_{01}}=1\pm(0.1+0.01+0.01)=1\pm 0.12.$$

It will be seen from (16) that in this case the largest error in comparison testing is introduced by the reflection factor of the oscillator with the known emf.

In the case when the impedance of the oscillator is considerably smaller than the characteristic impedance of the line (for instance, when the emf is taken across a low resistance),

$$\bar{\Gamma}_{0_1} = -(1-\Delta\bar{\Gamma}_{0_1}). \tag{17}$$

where $\Delta\Gamma_{0_1}$ is a small quantity.

By inserting (17) into (15) we obtain

$$\left|\frac{U_{on1}}{U_{01}}\right| = \left|\frac{\left(1-\frac{\Delta\bar{\Gamma}_{0_1}}{2}\right)(1-\bar{\Gamma}_{0_1}\bar{\Gamma}_L e^{-j2\beta d_1})}{[1+(1-\Delta\bar{\Gamma}_{0_1})\bar{\Gamma}_L e^{-j2\beta d_1}]}\right|. \tag{18}$$

For the least favorable phase combination we have

$$\frac{U_{on1}}{U_{01}} = \frac{\left(1\mp\frac{\Delta\Gamma_{0_1}}{2}\right)(1\mp\Gamma_0\Gamma_L)}{(1\pm\Gamma_L\mp\Delta\Gamma_{0_1}\Gamma_L)} \approx \tag{19}$$

$$\approx 1\pm\left(\frac{\Delta\Gamma_{0_1}}{2}+\Gamma_0\Gamma_L+\Gamma_L+\Delta\Gamma_{0_1}\Gamma_L\right).$$

In the case of a very small output impedance

$$\Gamma_{0_2}=-1;\quad \Delta\Gamma_{0_2}=0;$$

$$\left|\frac{U_{on2}}{U_{01}}\right| = \left|\frac{1-\bar{\Gamma}_{0_2}\bar{\Gamma}_L e^{-j2\beta d_2}}{1+\bar{\Gamma}_L e^{-j2\beta d_2}}\right|. \tag{20}$$

For the least favorable combination of phases we have

$$\frac{U_{on2}}{U_{01}} = \frac{1\pm\Gamma_{0_2}\Gamma_L}{1\mp\Gamma_L} \approx 1\pm\Gamma_L(1+\Gamma_{0_2}). \tag{21}$$

It will be seen from (21) that in this case the maximum error in comparison testing is due to the reflection factor of the comparator.

Eliminating the mismatching error by means of a phase shifter. By using a phase shifter in the comparator circuit it is possible to change its electrical length $\underline{d}$ and obtain a maximum and minimum reading of the comparator, i.e. for maximum and minimum voltages across the load:

$$U_{L1\,max} = U_{on1}\frac{|1+\bar{\Gamma}_L|}{1-|\bar{\Gamma}_0,\bar{\Gamma}_L|} \tag{22}$$

$$U_{L1\,min} = U_{on1}\frac{|1+\bar{\Gamma}_L|}{1+|\bar{\Gamma}_0,\bar{\Gamma}_L|} \tag{23}$$

$$U_{L2\,max} = U_{on2}\frac{|1+\bar{\Gamma}_L|}{1-|\bar{\Gamma}_0,\bar{\Gamma}_L|} \tag{24}$$

$$U_{L2\,min} = U_{on2}\frac{|1+\bar{\Gamma}_L|}{1+|\bar{\Gamma}_0,\bar{\Gamma}_L|}. \tag{25}$$

Having divided (22) by (23) we find

$$\left.\begin{aligned}\frac{U_{L1\,max}}{U_{L1\,min}} &= \frac{1+|\bar{\Gamma}_0,\bar{\Gamma}_L|}{1-|\bar{\Gamma}_0,\bar{\Gamma}_L|} = K_1\\ |\bar{\Gamma}_0,\bar{\Gamma}_L| &= \frac{K_1-1}{K_1+1}\end{aligned}\right\}. \tag{26}$$

From (24) and (25) we find in a similar manner

$$\left.\begin{aligned} \frac{U_{L2\,\max}}{U_{L2\,\min}} &= K_2 \\ |\bar{\Gamma}_0, \bar{\Gamma}_L| &= \frac{K_2-1}{K_2+1} \end{aligned}\right\}. \tag{27}$$

Having divided (24) by (22) we obtain after simple transformations the ratio of the nominal voltages of two oscillators which are compared by means of one load with a phase shifter (a variable length line):

$$\frac{U_{on2}}{U_{on1}} = \frac{U_{L2\,\max}\,(1+K_1)}{U_{L1\,\max}(1+K_2)}. \tag{28}$$

The same ratio expressed in terms of minimum values is equal to

$$\frac{U_{on2}}{U_{on1}} = \frac{U_{L2\,\min}}{U_{L1\,\min}} \cdot \frac{K_2}{K_1}. \tag{29}$$

Formulas (28) and (29) hold for any reflection factors of the compared oscillators. When the internal impedance of both oscillators is very small these formulas provide an accurate ratio of their emfs. In deriving (28) and (29) power losses in the shifter (variable length line) were considered to be negligible.

RADIATION MEASUREMENTS

IONIZATION CHAMBER USED AS A REFERENCE DEVICE FOR MEASURING THE ACTIVITY OF BETA-RADIATION PREPARATIONS

K. K. Aglintsev

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At present the unit of radioactivity, the curie, is reproduced by means of reference methods with the help of reference installations. In the range of beta-radiation activities from 10^{-11} to 10^{-7} curie reference installations consist of $4\pi\beta$ -counters which operate in a proportional or geiger condition. The use of scintillation counters with organic scintillators makes it possible to raise the upper limit of the measured activities up to 10^{-5} curie. In the range of 0.01 curie and higher reference installations consist of calorimeters. Thus, in the range of the measured activities of β -radiation preparations there is a gap of several orders between 10^{-5} and 10^{-2} curie.

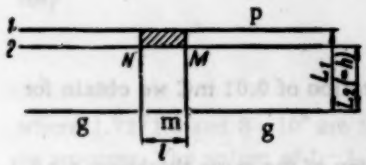


Fig. 1.

This gap can be successfully filled by using an ionization chamber of an extrapolation type whose schematic is shown in Fig. 1. The measuring electrode and the guard and potential electrodes around it are marked on the drawing by the letters m, g and p respectively. The effective area of the measuring electrode is $S = \pi l^2/4$, where l is equal to the sum of the measuring electrode diameter and half the gap between it and the guard electrode. The two positions of the potential electrode 1 and 2 correspond to distances L_1 and L_2 to the measuring electrode, the two values of the measuring volume $V_1 = L_1S$ and $V_2 = L_2S$, and the two ionization currents I_1 and I_2 expressed in amperes. The diameter of the measured preparation in all cases is assumed to be equal to that of the measuring electrode.

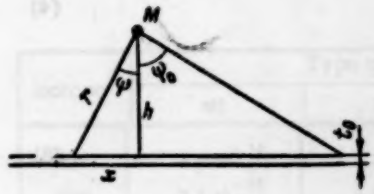


Fig. 2.

When the electrode of the extrapolation chamber is moved from position 1 to position 2 the measuring volume is changed by V_1-V_2, and the corresponding variation in the ionization current will be I_1-I_2. In Fig. 1 the volume V_1-V_2 is shaded.

Let us now examine some specific and easily calculable conditions of ionization chamber operation. Let us assume that $S = 0.1$ cm^2, $L_1 = 6$ mm, $L_2 = 5$ mm, $V_1-V_2 = 0.01$ cm^3. For measuring the activity let us take isotope preparations with different values of the β -spectrum maximum energy: S^{35} (167 kev), W^{185} (430 kev), Tl^{204} (765 kev), Y^{91} (1560 kev) and P^{32} (1690 kev). We shall assume the specific activity of these preparations to be $q = 1$ C/g, and the density of their substance to be $\rho = 1$ g/cm^3. Let us assume that the thickness of the preparations is small and equal to 0.1 mg/cm^2, so that the self-absorption of β -radiations in the source even in the case of the softest β -radiator, namely S^{35}, can be neglected.

The activity of the measured preparations for a given specific activity, thickness and area will obviously be equal to 0.01 mC. Such a preparation will radiate $3.7 \cdot 10^5$ β -particles per second within a solid angle of 4π.

Volume V_1-V_2 under the above-described conditions will be seen from the radiation source under a solid angle approaching 0.024 [1] and, hence, this volume will be penetrated by $9 \cdot 10^3$ β -particles per second. The dose rate P produced by these β -particles in the volume of V_1-V_2 can be found from the data given in [2], and for the above-mentioned isotopes will have the following values: 12, 7, 4, 3.3 and 3.2 expressed in units of 10^{-3} rads/sec. For S^{35} the absorption of β -particles in the layer of air 5 mm thick was taken into account, and the correction amounts to 14%.

A bad energy resolution is distinctly noticeable and is due to the fact that the characteristic of the dose D_1 per β-particle as given in [2] approaches a straight line parallel to the X-axis at energies above 800 kev. An improved power resolution and a simultaneous rise in the difference $I_1 - I_2$ up to conveniently measurable values can be attained by increasing the thickness and area of the measured preparations.

The computations given below for preparations of a larger diameter are based on the assumption that an exponential absorption law holds for β-radiations, i.e. that the dose P(rads/sec) at a distance r from a point source is expressed by the relation

$$P = \frac{CA}{r^2} e^{-\mu r}, \tag{1}$$

where A is the activity in mC; μ is the absorption coefficient.

Coefficient C is obtained from [3]:

$$C = \frac{kE\mu}{4\pi}, \tag{2}$$

where k is a coefficient whose numerical value depends only on the chosen units; E is the mean energy of a β-spectrum, kev.

Thus we have

$$P = \frac{kAE\mu e^{-\mu r}}{4\pi r^2} = \frac{0.7\, kAE e^{-\mu r}}{4\pi r^2 \Delta}, \tag{3}$$

where $\Delta = 0.7/\mu$, mg/cm², is the half-value layer for β-particles.

Using the above value of the dose rate at a distance of 5 mm from the preparation of 0.01 mC we obtain for k the value of 0.5.

Let us now find the dose rate produced at point M (see Fig. 1) of the preparation of the same thickness $t_0 = 0.1$ mg/cm² but with an area of S = 10 cm². From (3) we obtain (Fig. 2)

$$P = \int_v \frac{0.7kEqt_0 e^{-\mu r}}{4\pi r^2 \Delta} 2\pi x dx, \tag{4}$$

or after transformations

$$P = \frac{0.7kEqt_0}{2\Delta}\left[-\{-Ei(-\mu h)\} - \{-Ei(-\mu h \sec\psi_0)\}\right]. \tag{5}$$

It can easily be shown that at the periphery of the measuring volume at point N (see Fig. 1) the dose rate will amount, depending on the maximum energy of the β-spectrum, to 35-40% of its maximum value obtained from (5). The mean value of the dose rate over the whole measured volume amounts to 40-50% of its maximum value. Calculations provide the following mean values of the dose for the aforementioned isotopes: 0.12, 0.10, 0.09, 0.07, and 0.07 rad/sec and maximum values of 0.3, 0.25, 0.18, 0.13, and 0.125 rad/sec.

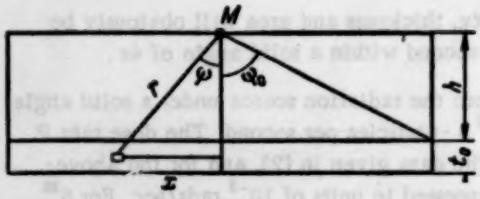


Fig. 3.

Let us now deal with a "thick" preparation whose thickness amounts to $t_0 = 100$ mg/cm². Let us denote the depth of a certain volume element dv of the source, calculated from its surface, by t. We obtain (Fig. 3)

$$dP = \frac{kq2\pi\, x dx\, dt E e^{-\mu r} 0.7}{4\pi r^2 \Delta}. \tag{6}$$

Substituting expressions x and r by t + h and ψ and integrating we find, by denoting the sum $t_0 + h$ by T, that

$$P = \frac{kqE}{2}\left[\int_0^{\psi_1} e^{-\mu h \sec\psi} \sin\psi d\psi - \int_0^{\psi_2} e^{-\mu T \sec\psi} \sin\psi d\psi\right] \quad (7)$$

or expressing the integrals in (7) by King's function $\Phi(x)$ [4] we have

$$P = \frac{kqE}{2}[\Phi(\mu h) - \cos\psi_0 \Phi(\mu h \sec\psi_0) - \Phi(\mu T) + \cos\psi_0 \Phi(\mu T \sec\psi_0)], \quad (8)$$

where

$$\Phi(x) = e^{-x} - x\int_x^{\infty} e^{-t}\frac{dt}{t}. \quad (9)$$

The following dosage rates at point M are obtained by calculation from (8) for the isotopes under consideration: 7.5, 24, 42, 64 and 66 rads/sec. The dosage rate at point N will amount to 28-32% of the maximum value, and the mean rate over the whole measuring volume will be 38-42% of the maximum value, i.e. 2.8, 9.5, 17, 27 and 28 rads per sec.

With the knowledge of the dosage rate and the measuring volume it is possible to find $I_1 - I_2$ from the relationship

$$I_1 - I_2 = \frac{P(V_1 - V_2)}{3 \cdot 10^9} \cdot \frac{1.72}{1.6},$$

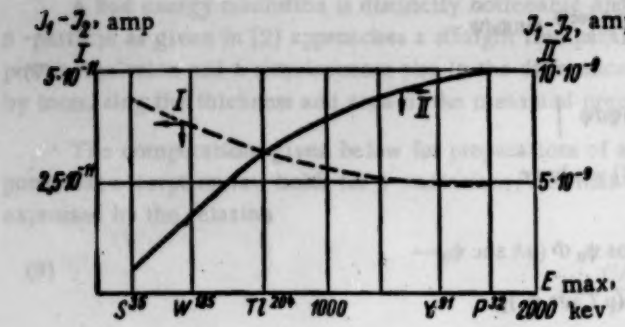
where 1.72/1.6 and $3 \cdot 10^9$ are factors for converting rads to physical roentgen equivalents and CGSE units of current to amperes. The values of $I_1 - I_2$ for the three types of sources under consideration are given in the attached table. Source No. 1 has S = 0.1 cm^2, t_0 = 0.1 mg/cm^2; Source No. 2 has S = 10 cm^2, t_0 = 0.1 mg/cm^2; and No. 3 has S = 10 cm^2, t_0 = 100 mg/cm^2.

Isotope	Type of source		
	№1	№2	№3
S^{35}	$4.0 \cdot 10^{-14}$	$4.3 \cdot 10^{-11}$	$1.0 \cdot 10^{-9}$
W^{185}	$2.5 \cdot 10^{-14}$	$3.7 \cdot 10^{-11}$	$3.4 \cdot 10^{-9}$
Tl^{204}	$1.5 \cdot 10^{-14}$	$3.2 \cdot 10^{-11}$	$6.1 \cdot 10^{-9}$
Y^{91}	$1.3 \cdot 10^{-14}$	$2.5 \cdot 10^{-11}$	$9.5 \cdot 10^{-9}$
P^{32}	$1.2 \cdot 10^{-14}$	$2.5 \cdot 10^{-11}$	$9.9 \cdot 10^{-9}$

It will be seen from the above data that for thin sources of an area of 10 cm^2 the value of $I_1 - I_2$ is about 1000-2000 times larger than for sources of the same thickness but with an area of 0.1 cm^2. This is due to the fact that in a source of the type of No. 2 the measuring volume $V_1 - V_2$ is 100 times larger than for source No. 1, and the mean value of the power in the measuring volume is also 10-20 times greater. Increasing the thickness of the sources 1000 times will provide a rise in the ionization current for the isotopes in question by factors of 23, 92, 190, 380 and 395 respectively. It is natural that increasing the thickness has a smaller effect on isotopes with soft β -spectra than on those with hard β -spectra.

Fig. 4 shows the relation between $I_1 - I_2$ and the maximum energy in the β -spectrum for all the sources under consideration. The dotted line refers to sources of the No. 2 type and the full line to those of the No. 3 type. It will be seen from Fig. 4 that the full line provides a much higher power resolution.

Let us also note the following. Sources type No. 3 provide differences of $I_1 - I_2$ of the order of 10^{-9} amp, but these sources contain 1 curie. Hence, for the activity range of 10^{-2} to 10^{-5} curie which is of interest to us, we obtain the following: if the activity of the preparation is 10^{-2} curie, then for t_0 = 100 mg/cm^2 and S = 10 cm^2 the difference $I_1 - I_2$ will lie in the range of 10^{-11} to 10^{-10} amp; if the activity of such sources is 10^{-5} curie the difference $I_1 - I_2$ will be in the range of 10^{-14} to 10^{-13} amp. This indicates that such sources provide conveniently measured values of the ionization current. In general in an ionization chamber the value of $I_1 - I_2$ will depend on the type of isotope, its specific activity in the preparation, and the area and thickness of the source.



Thus, the following technique for measuring activity by means of extrapolation type chambers can be recommended. The measured source must be "thick", of the order of 100 mg/cm^2, and have an area of the order of 10 cm^2. The optimum value of the specific activity of the preparation lies in the range of 10^{-2} to 10^{-4} mC/mg. For a specific activity of 10^{-5} mC/mg the difference I_1-I_2 for soft radiators will be of the order of 10^{-14} amp; it is obviously more convenient to measure larger currents. In this case, as in reference calorimetric installations the preparation must be chemically pure since any admixtures of other isotopes will distort the measurement results. Contrary to calorimetric measurements, in this instance it is necessary to know in advance the specific activity of the measured preparations.

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DETERMINING THE RESOLUTION TIME OF A COUNTER

V. M. Prokhorov

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The normal method of determining the dead time of a counter [1-2] includes the measurements of the combined counting rate of two radioactive preparations, kept simultaneously in a protective casing. This operation is sometimes difficult to fulfill for various reasons. The method advocated by us eliminates these difficulties.

A metal filter of a given thickness transmits a constant portion of radiation of a known radiator, irrespective of the activity of the source, i.e.

$$\frac{I_0}{\bar{I}_0}=\text{const}=A. \tag{1}$$

where I_0 is the preparation's intensity of radiation; $\bar{I}_0$ is the intensity of radiation of the same preparation but after passing through the filter; A is the filter multiplicity factor.

By expressing the actual number of particles which penetrate to the volume of the counter in terms of the counted pulses I and the resolution time τ in accordance with the well-known formula

$$I_0=\frac{I}{1-I\tau}, \tag{2}$$

we obtain

$$\frac{\dfrac{I}{1-I\tau}}{\dfrac{\bar{I}}{1-\bar{I}\tau}}=A. \tag{3}$$

Solving (3) with respect to τ we have

$$\tau = \frac{A\bar{I} - I}{\bar{I}I(A-1)}. \quad (4)$$

The multiplicity factor A of the filter is determined as the ratio of the counting rate without the filter and with the filter for a source with a sufficiently small activity which does not require correction for dead time. Thus, if the multiplicity factor of the filter is found in advance, the resolution time of the counter can be determined in two instead of three measurements. Hence, this method is especially convenient for determining this parameter for a large number of counters of the same type.

Calculations show that the relative error in determining τ, which is expressed by the formula

$$\delta\tau = \left[\frac{2A}{I\tau(A-1)} - 1\right]\delta I, \quad (5)$$

where δI is the relative error of I and $\bar{I}$, is smaller than the error of the usual measuring method by a factor of $2(A-1)/A$ taken under similar conditions (with the maximum counting rate, τ, and $\delta\tau$ being equal). The accuracy of the method increases with a rising A and I.

However, for large values of $I\tau$ the basic formula (2) does not fully apply, since it was derived [3] from the relation

$$I = I_0 e^{-I_0\tau} \quad (6)$$

by replacing $e^{-I_0\tau}$ by $(1 + I_0\tau)^{-1}$, which is only permissible for $I_0\tau \ll 1$. For large values of $I\tau$ it is possible to use another version of this method based on equation (6).

The ratio of the counting rate of the source without a filter to that with a filter in this case will be

$$\frac{I}{\bar{I}} = \frac{I_0}{\bar{I}_0} e^{-\tau(I_0 - \bar{I}_0)} = A e^{-\bar{I}_0\tau(A-1)},$$

whence

$$\tau = \frac{1}{\bar{I}_0(A-1)} \ln \frac{\bar{I}A}{I}.$$

Taking into consideration that $\bar{I}_0\tau$ is smaller than $I_0\tau$ by a factor of A we assume that

$$\bar{I}_0 \approx \frac{\bar{I}}{1 - \bar{I}\tau},$$

and we finally obtain

$$\tau \approx \frac{\ln \frac{A\bar{I}}{I}}{\bar{I}\left(A - 1 + \ln \frac{A\bar{I}}{I}\right)}. \quad (7)$$

The table shows the comparison of the two methods as applied to counter MST-17 with a radiation source of $Sr^{90} + Y^{90}$.

It will be seen from the table that both methods provide similar results which do not differ by more than 20%, which does not exceed the error of measurements.

Conclusions. The above method is based on the fact that a filter with a constant thickness absorbs a constant radiation fraction of the source. The method does not require that two preparations be measured simultaneously in one casing, it reduces the number of required measurements when repeated determination of the resolution time is made and is as accurate as the normally used method.

Measurement No.	Measuring method		
	normal	according to the formula	
		(4)	(7)
	τ·10⁶ min		
1	5.3	4.7	4.4
2	5.0	3.6	3.5
3	4.5	4.2	4.0
mean	$4.9 \cdot 10^{-6}$ min	$4.2 \cdot 10^{-6}$ min	$4.0 \cdot 10^{-6}$ min

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STATISTICAL CHECKING OF RADIOMETRIC EQUIPMENT

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Statistical checking of radiometric equipment makes it possible to discover in good time defects which lower the accuracy of measurements. Such checking is also useful because unstable readings of the instrument cannot always be discovered by the usual methods. This is particularly the case when the interference is not excessive or measurements are made under conditions when the whole of the required checking equipment cannot be used.

The checking is based on the assumption that the number of pulses in a satisfactorily working instrument is distributed according to Poisson's law. This assumption is theoretically sound and has been confirmed experimentally.

The only drawback of this method consists in the fact that it cannot bring to light defects which are also distributed according to Poisson's law. However, all the actually encountered sources of interference, such as aging of Geiger counters, unstable operation of photomultipliers, incorrect adjustment of discriminators, amplifiers, recording and supply units, defects in the electromechanical counters, etc. provide interferences differing distinctly from the Poisson type. Hence, the above drawback is of no practical importance.

The essence of the checking method under consideration consists in evaluating the relation $f \cdot S^2/\bar{x}$, which is obtained from a series of measurements:

$$f \cdot \frac{S^2}{\bar{x}} = \frac{\sum_1^n (x_i - \bar{x})^2}{\frac{1}{n}\sum_1^n x_i}. \quad (1)$$

The instrument is considered to be working satisfactorily if this quantity satisfies the inequality

$$\frac{\chi^2_{\alpha/2}}{f} < \frac{S^2}{\bar{x}} < \frac{\chi^2_{1-\alpha/2}}{f} \quad (2)$$

for bilateral checking, or the inequality

$$\frac{S^2}{\bar{x}} < \frac{\chi^2_{1-\alpha}}{f} \quad (3)$$

for unilateral checking at a given significance level α, where $\underline{x}$ is the number of readout pulses; $\underline{k}$ is the number of measurements; f is the number of degrees of freedom; χ^2 is the sum of the squares of normalized random quantities distributed according to the normal law.

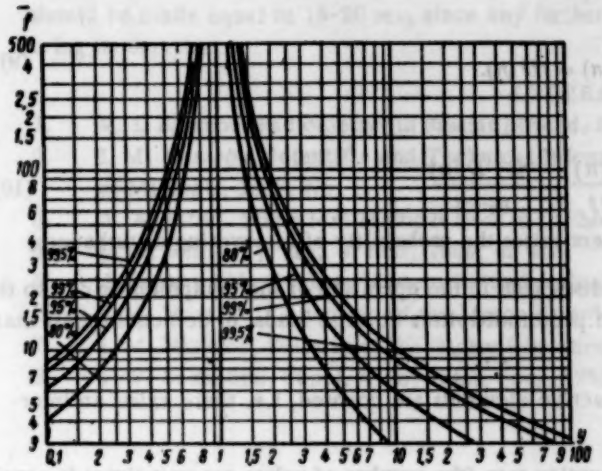

Fig. 1. Nomogram for determining the number of measurements for which the deviation $y = \sigma^2/\bar{x}$ from the expected dispersion is discovered with the probability of $p(\sigma^2)$ in the case of a bilateral criterion χ^2 for $\alpha = 0.05$.

If the instrument is unsatisfactory we obtain

$$M(S^2) = \sigma^2 + M(\bar{x}) \tag{4}$$

and the preceding inequalities become equivalent to

$$\chi^2_{\alpha/2}\frac{\bar{x}}{\sigma^2} < \chi^2 = f\frac{S^2}{\sigma^2} < \chi^2_{1-\alpha/2}\frac{\bar{x}}{\sigma^2};$$
$$\chi^2 = f\frac{S^2}{\sigma^2} < \chi^2_{1-\alpha}\frac{\bar{x}}{\sigma^2}; \tag{5}$$

in which σ^2 denotes the instrument readings dispersion, whose component consists of the interference dispersion.

It follows from (5) that the probability of discovering the interference is

$$p_1 = p\left[\chi^2 < \chi^2_{\alpha/2}\frac{\bar{x}}{\sigma^2}\right] + p\left[\chi^2 > \chi^2_{1-\alpha/2}\frac{\bar{x}}{\sigma^2}\right] \tag{6}$$

or

$$p_2 = p\left[\chi^2 > \chi^2_{1-\alpha/2}\frac{\bar{x}}{\sigma^2}\right]. \tag{7}$$

Figs. 1 and 2 show a family of curves of the relation between the degrees of freedom f and the quantity $y = \sigma^2/\bar{x}$ for various values of p_1 and p_2 at a significance level $\alpha = 0.05$.

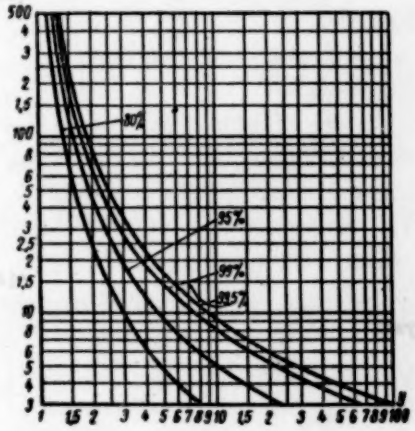

Fig. 2. Nomogram for determining the number of measurements for which the deviation $y = \sigma^2/\bar{x}$ from the expected dispersion is discovered with the probability $p(\sigma^2)$ in the case of a unilateral criterion χ^2 for $\alpha = 0.05$.

These curves provide for a given interference level, i.e. for a given value of $\underline{y}$ and a given confidence probability, the number of degrees of freedom $f = k - 1$, i.e. the number of required measurements. The same curves can solve the opposite problem of finding $\underline{y}$ for given values of f and p_1 or p_2.

The reliability of the above checking method rises with the number of measurements. However, the total time of check measurements is limited and, hence, their number can only be raised if the duration of each measurement is reduced. It can be shown that a reduction in the duration of each measurement provides a more flexible and reliable checking of the equipment's operation.

In continuous testing it is always possible to raise the duration of separate measurements by adding up adjacent readings.

Let us now examine two cases which are of interest from the practical point of view. For this purpose let us denote n_0 as the expectation value of the number of pulses per time unit distributed according to Poisson's law ($n_0 t = x_0$ is Poisson's distribution parameter); $\underline{n}$ is the expectation value of the number of pulses per unit time due to equipment interference.

1. $\underline{n}$ is a random value independent of n_0. Interference of this type is present in unstable photomultipliers, incorrectly adjusted electronic circuits, etc.

In this case

$$M(S^2) = M(S_1^2) + M(S_2^2) = n_0 t + D(nt). \tag{8}$$

where D(nt) is the dispersion of the number of pulse disturbances per measuring interval t.

Let us denote the number of pulse disturbances per unit time by D(n). Then we shall have

$$D(nt) = \sum_1^t D(n) = tD(n). \tag{9}$$

Hence y does not depend on time:

$$y = \frac{M(S^2)}{M(\bar{x})} = \frac{n_0 t + tD(n)}{(n_0+n)t} = \frac{n_0 + D(n)}{n_0+n}. \tag{10}$$

Thus, in this case a reduction in the duration of a measurement raises the probability of discovering disturbances.

2. The equipment's sensitivity varies linearly. Such a disruption in the operation of the equipment is due to the zero drift in the electronic circuits, a drop in the emission of photomultipliers at large loads, or defects in their manufacture, etc.

In such cases only the pulses due to radiations of radioactive elements are counted, i.e. there exists an interrupted Poisson process.

If at the initial instant the expectation value of the counting rate (the number of pulses per unit time) is equal to n_0, then at instant t the expectation value will hold for

$$M(x) = n_0 + \varepsilon t, \tag{11}$$

where ϵ is a coefficient showing the rising or falling of the counting rate per unit time.

The expectation value and dispersion of the pulses counted during this time are equal to

$$M(x) = D(x) = n_0 t + \varepsilon t^2/2. \tag{12}$$

Let the total time of continuous measurements be T. The expectation value $\bar{x}$ will then be equal to

$$M(\bar{x}) = \frac{1}{\kappa}\sum_1^\kappa M(x_i) = \frac{1}{\kappa}(n_0 T + \varepsilon T^2/2). \tag{13}$$

Let us now calculate the expectation value S^2:

$$M(S^2) = \frac{1}{\kappa}\sum_1^\kappa M[x_i - M(\bar{x})]^2 =$$

$$= \frac{1}{\kappa}\sum_1^\kappa \{[x_i - M(x_i)] + [M(x_i) - M(\bar{x})]\}^2$$

$$\sum_1^\kappa M[x_i - M(x_i)]^2 = \sum_1^\kappa D(x_i) = n_0 T + \varepsilon T^2/2 \tag{14}$$

$$2\sum_1^\kappa M[x_i - M(x_i)][M(x_i) - M(\bar{x})] = 0$$

$$\sum_1^\kappa [M(x_i) - M(\bar{x})]^2 \approx \frac{\varepsilon^2 T^4}{12\kappa}.$$

Hence

$$y = \frac{M(S^2)}{M(\bar{x})} = 1 + \frac{\varepsilon^2 T^4}{12\kappa(n_0 T + \varepsilon T^2/2)}, \tag{15}$$

i.e. it decreases with the duration of a measurement.

An analysis by means of the curves in Figs. 1 and 2 shows that the reduction of the duration of measurements results in the reduction of the probability of detecting the sensitivity variations in the equipment.

Thus, for a more efficient checking the value of $f \cdot S^2/\bar{x}$ should be calculated twice, first for large values of k and then for small values with a preliminary adding of adjacent results.

The shortest duration of a measurement is limited by the condition $n_0 t > 1$. However, in practice this limit should be made equal to 15-20 sec, since any further reduction of this interval leads to inadmissible errors in measuring its duration.

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LIQUID AND GAS FLOW MEASUREMENTS

MEASUREMENT OF TWO-PHASE FLOWS BY MEANS OF VENTURI TUBES

A. A. Shatil'

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In hydraulic and pneumatic conveyor practice two-phase flows whose dispersing medium consists of a liquid or gas and the dispersed phase of solid particles are sometimes measured by means of standard constricting devices (Venturi tubes) with the application of appropriate equations intended for pure liquids and gases. The specific gravity in these equations is evaluated as that of a two-phase flow.

The pressure drop in the constricting device depends not only on the mean specific gravity γ_{ds} of the dispersion system, but also on the specific gravity γ_d of the dispersed phase and on the degree of its pulverization. This phenomenon is due to unequal velocities of the medium v_m and the phase v_d produced by the acceleration in the constricting device which occurs for specific gravities γ_m and γ_d which differ considerably from each other. If in using normal flow equations this fact is ignored, considerable differences between the measured and actual flow will be obtained.

At present there are as yet no clear and substantiated rules on the applicability of normal flow equations to two-phase flows. At most only certain empirical coefficients [1, 2] are recommended, which account for the effect of the solid phase.

Let us now analyze a two-phase flow in a horizontal Venturi tube (Fig. 1). In a two-phase flow which has a high degree of solid phase dispersion (or a small difference between the specific gravities of the medium and the phase), the difference in the velocities of the phase and the medium in the constricting channel of a Venturi tube approaches zero. In this case it is possible to write for pressure drop Δp_{ds} the well-known equation

$$\Delta p_{ds} = \frac{1}{\alpha^2 m^2} \frac{v_{ds_1}^2}{2g} \gamma_{ds}, \tag{1}$$

where α is the rate of flow coefficient; m is the ratio of the narrow and wide section areas in the Venturi tube; v_{ds_1} is the mean velocity of the flow in the pipe line, m/sec; g is the acceleration of a freely flowing body, m/sec^2.

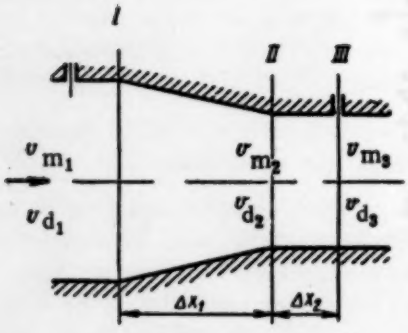

Fig. 1.

The specific gravity of the dispersed system is calculated from the equation

$$\gamma_{ds} = \frac{Q_d \gamma_d + Q_m \gamma_m}{Q_d + Q_m}, \tag{2}$$

where Q_d and Q_m are the phase and medium flow respectively, m^3/sec.

In a particular case which is important from the practical point of view, when $Q_d/Q_m = \mu \gamma_m/\gamma_d \ll 1$, the specific gravity of the dispersion system can be assumed with sufficient accuracy to be equal to

$$\gamma_{ds} = \gamma_m(1+\mu), \tag{2'}$$

where μ is the ratio of the phase and medium flows measured by weight.

When the phase and the medium have different velocities due to the acceleration in the restricting channel, the loss of head dissipated on the acceleration of the solid particles should be accounted for separately.

For this purpose it is possible to use the momentum equation

$$\Delta p_d = M_d \Delta v_d \tag{3}$$

where M_d is the mass rate of flow of the phase per second through a unit cross section, the rate being equal to $\mu(\gamma_m/g)v_m$, kg-wt·sec/m³; Δv_d is phase velocity change in m/sec produced in the acceleration section Δx.

The momentum equation can be represented for the Venturi tube portion between cross sections I and III (Fig. 1) in the following form:

$$\Delta p_d = \mu \frac{\gamma_m}{g} \int_{x_1}^{x_3} v_m \frac{dv_d}{dx} dx. \tag{3'}$$

The integration is carried out from cross section I with coordinate x_1 to cross section III with coordinate x_3.

It can be assumed that the loss of head which produces the two-phase flow acceleration consists of the losses producing the accelerations of the medium and the phase particles.

The total loss of head producing the accelerations of the medium and the phase will then be equal to

$$\Delta p_{ds} = \frac{1}{a^2 m^2} \cdot \frac{v_{m_1}^2}{2g} \gamma_m + \mu \frac{\gamma_m}{g} \int_{x_1}^{x_3} v_m \frac{dv_d}{dx} dx, \tag{4}$$

or

$$\Delta p_{ds} = \frac{1}{a^2 m^2} \cdot \frac{v_{m_1}^2}{2g} \gamma_m (1 + k\mu), \tag{5}$$

where

$$k = \frac{2a^2 m^2}{v_{m_1}^2} \int_{x_1}^{x_3} v_m \frac{dv_d}{dx} dx. \tag{6}$$

Equation (5) can also be written in the form of a formula

$$\Delta p_{ds} = \Delta p_m (1 + k\mu), \tag{7}$$

which is fairly widely used in calculating the hydraulic resistance of pipelines [1, 3] and agrees well with experimental results. In certain cases and within certain limits [4, 5] coefficient $\underline{k}$ is independent of the concentration and rate of flow.

Coefficient $\underline{k}$ for the Venturi tube can be calculated from the following equation [6]:

$$k = 2a^2 m \left[\frac{m+1}{2} (\varphi_{1-2} - 1) + \varphi_{1-2} (\varphi_{2-3} - 1) \right], \tag{8}$$

where φ_{1-2} is the ratio of the phase velocities in cross sections II and I; φ_{2-3} is the ratio of the phase velocities in cross sections III and II.

The values of φ_{1-2} and φ_{2-3} are determined from the graph given in Fig. 2, which represents the relationship

$$\varphi = f(C\Delta x;\ \beta), \tag{9}$$

which has been obtained by analyzing the accelerated motion of particles in a constricted channel [6].

The value of $C\Delta x$, which represents 0.75 of Stokes's criterion, amounts to

$$St = \psi \frac{\Delta x}{d_d} \cdot \frac{\gamma_m}{\gamma_d}, \tag{10}$$

and determines the aerodynamic properties of particles in the given medium (more precisely, the relation between the aerodynamic forces of resistance and the forces of inertia). Here ψ is the coefficient of the hydraulic resistance

of particles, which is a function of Re_d [7]; Δx is the length of the acceleration portion, m; d_d is the diameter of particles, m.

Coefficient

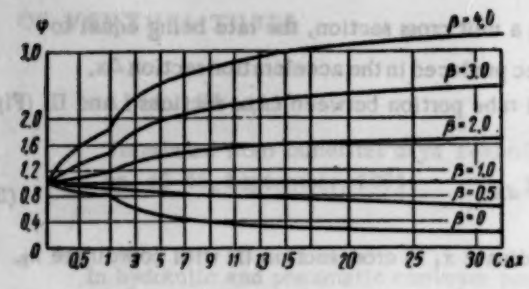

Fig. 2.

$$\beta = \frac{v_{m_1}}{v_{d_1}} + \frac{v_{m_2}}{v_{d_1}} - 1 \qquad (11)$$

characterizes the conditions of the particle movements, which are mainly related to the configuration of the channel. For a constricting portion of the Venturi tube, for instance, where $v_{m_1} = v_{d_1}$,* coefficient β is equal to 1/m.

It will be seen from (2') and (5) that the actual rate of the two-phase flow is equal to

$$G_{act} = v_{m_1} F_1 \gamma_{ds} = \alpha m F_1 \sqrt{2g\Delta p_{ds} \gamma_{ds} \frac{1+\mu}{1+k\mu}} \qquad (12)$$

(here F_1 is the pipeline cross section). On the other hand, a formal use of the generally accepted rate of flow formula provides

$$G_{ms} = \alpha m F_1 \sqrt{2 g \Delta p_{ds} \gamma_{ds}}. \qquad (13)$$

Thus we can write

$$G_{act} = K G_{ms}, \qquad (14)$$

where

$$K = \sqrt{\frac{1+\mu}{1+k\mu}}.$$

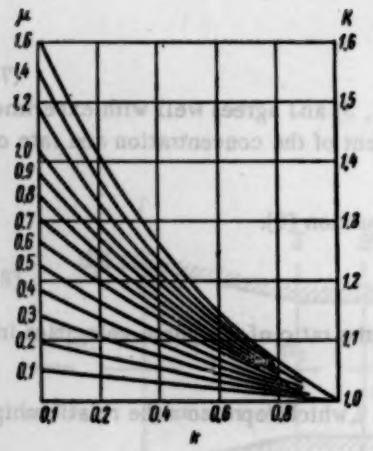

Fig. 3.

Fig. 3 shows the effect of coefficient k on the relation between the actual and measured rates of flow for different values of μ. It will be seen from the graphs that for $k > 0.7$ and $\mu < 0.5$ the error in using the normal rate of flow formula (13) amounts to less than 5%.

In order to illustrate the above considerations the attached table shows the computed coefficients k for a normal Venturi tube (D = 100 mm, d = 70 mm, α = 1.13) for four different dispersion systems.

The technique in computing k is described in detail in [6]. Here it is only necessary to note that in the first line of each of the cases under consideration the computation is made for an acceleration portion Δx_1, and in the second line for portion Δx_2. The values of φ_{1-2} and φ_{2-3} are obtained by calculation and inserted in (8). Reynolds' criterion is calculated from the formula $Re_d = Wd_d/\nu$, where W is the relative velocity of the particles and the resistance coefficient is calculated from the formula $\psi = 24/Re_d + 4/\sqrt[3]{Re_d}$.

It will be seen from the table, which represents two-phase systems consisting of soot and air ($\gamma_d/\gamma_m \approx 1500$) and of cinders and water ($\gamma_d/\gamma_m \approx 2$) for values of $C\Delta x$ exceeding 10, that coefficient k approaches unity. Hence, for cases 1 and 3 the use of (13) for values of μ up to 1.5 will produce an error not exceeding 2-3% (Fig. 3). In cases 2 and 4 the same error will be obtained only for values of μ not exceeding 0.1.

We do not claim the above calculations to be an accurate and exhaustive analysis of the problem; however, they represent to some degree the physical essence of the phenomenon. The calculation of coefficient k serves in each specific case to determine the lagging of the solid particles from the flow, and the graph in Fig. 3 gives an approximate evaluation of the error in measuring the rate of a two-phase flow by means of generally accepted equations.

*It is assumed that in the pipeline before the constriction the velocities of the medium and the solid phase are equal.

№	γ_m, kg/m³	γ_d, kg/m³	d_d, m	Δx, m	β	W^*, m/sec	v_{m_1}, m/sec	v_{m_2}, m/sec	v_{d_1}, m/sec	v_{d_2}, m/sec	Re_d	ψ	C^{**} 1/m	$C\Delta x$	φ	k
1	1.33	2000	20.10^{-6}	0.081 0.035	2.04 1.8	3.3 4.45	15 30.6	30.6 30.6	15 24	24 28.3	4.4 5.9	7.9 6.3	197 157	16.0 11.0	1.6 1.18	0.91
2	1.33	2000	200.10^{-6}	0.081 0.035	2.04 2.82	7.3 13.95	15 30.6	30.6 30.6	15 16	16.0 17.3	97 186	1.12 0.829	3.73 2.76	0.302 0.096	1.07 1.08	0.17
3	1000	2000	2.10^{-3}	0.081 0.035	2.04 1.72	0.54 0.75	2 4.08	4.08 4.08	2 3	3 3.66	1080 1500	0.45 0 44	112 109	9.1 7.5	1.5 1.22	0.87
4	1000	2000	20.10^{-3}	0.081 0.035	2.04 2.48	0.87 1.55	2 4.08	4.08 4.08	2 2.34	2.34 2.72	17400 31000	0.44 0,47	11 11.7	0.89 0.41	1.17 1.16	0.39

$$^{*}W=\frac{v_{m_1}+v_{m_2}}{2}-\frac{v_{d_1}+v_{d_2}}{2}$$

$$^{**}C=\frac{3}{4}\frac{\psi}{d_n}\cdot\frac{\gamma_m}{\gamma_d}$$

In making these calculations it should be borne in mind that in the case of a polydispersed solid phase, the diameter d_d of spherical particles which are hydrodynamically equivalent to such a phase will be considerably smaller than the mean weighted or most probable diameter. It should also be noted that with rising dimensions of a normal Venturi tube, coefficient k will increase and approach unity due to the rise in Stokes's criterion (quantity $C\Delta x$).

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EQUIPMENT FOR DETERMINING THE FREQUENCY CHARACTERISTICS OF DIFFERENTIAL MANOMETER FLOWMETERS

M. A. Gol'dinov

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In order to measure the quantity (volume or mass) of gases flowing through a pipeline, recording differential manometer flowmeters are widely used with circular or rectangular charts. In certain instances these instruments are supplied with a device for extracting the square root of the measured pressure difference, thus providing a uniform rate of flow scale. The error in recording a variable rate of flow signal and, hence, the error in measuring the quantity of gas,depends to a great extent on the dynamic characteristics of the differential manometer. Research carried out by the All-Union Scientific Research Institute of the Committee of Standards, Measures and Measuring Instruments

(VNIIK) shows that in extracting the square root of the pressure difference value by means of the distorted dynamic system of the instrument, excessive rate of flow integration errors may arise which cannot be compensated with respect to time and depend on the spectrum of the measured process.

In order to determine the integration errors and establish the spectrum boundaries of the process which can be measured by means of a differential manometer flowmeter, it is necessary to know the dynamic characteristics of the process. Such characteristics for certain types of differential manometer transducers were obtained experimentally [1, 2]. The VNIIK has developed a test installation by means of which it is possible to obtain the frequency characteristics and transfer functions of recording differential manometers. The equipment consists of a drive, a harmonic pressure oscillation generator, and an apparatus for measuring the input and output signals which includes recording transducers, electronic amplifiers, and a moving coil oscillograph type MPO-2. The drive of the equipment provides a continuous variation of the input signal frequency from 0.006 to 2 cps.

The harmonic pressure oscillation generator consists of a link mechanism and a jet pneumatic transducer (Fig. 1) developed by the author of this article. The rotation of the link disc, connected to a drive which provides the sinusoidal movement of the rod of the mechanism, stresses a spring whose tensile effort is transmitted to a pneumatic transducer. The air in the transducer is propelled from the supply source through nozzle 1 to tube 3, which is connected to bellows 2. The air pressure in the bellows provides an effort which balances through a feed-back system (lever 4 and flexible rod 5) the tension in springs 6 and 7 which react with the nozzle.

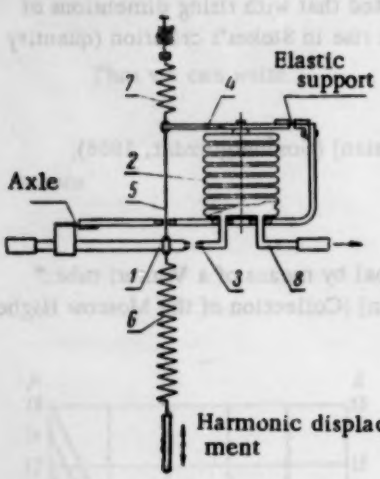

Fig. 1.

The above device provides virtually sinusoidal pressure variations in the positive chamber of the tested differential manometer, which is connected to the transducer through a short connecting pipe 8. The input pressure amplitude is varied by selecting appropriate openings for the nozzle and the pipe and adjusting the distance between them. The constant pressure component is set by tensioning spring 7. The pressure transmitted by the vibration generator to the positive chamber of the tested differential manometer (its negative chamber is connected to the atmosphere) is measured by means of strain gauge transducers connected to the 4-channel strain gauge ac amplifier type TU-4M, which has a circuit similar to that used in LPI amplifiers [3]. In the strain gauge transducer (Fig. 2) the pressure is fed to diaphragm unit 1; the effort developed by the unit strains plate 2, whose sensing wire grids 3 are glued and connected to a single unbalanced bridge. The other two arms of the bridge consist of the compensating wire grids 4, which are glued to the transducer base. The imbalance voltage is fed to the input of the strain-gauge amplifier which supplies the bridge with a voltage of 5–7 v at a carrier frequency of 6000 cps. The voltage across the measuring diagonal of the bridge is detected, passed through a filter which suppresses the carrier frequency, and fed to vibrator type V of the MPO-2 oscillograph.

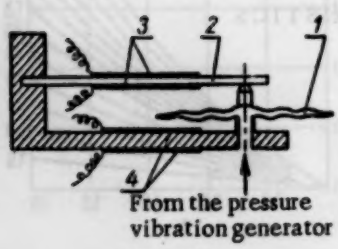

Fig. 2.

The displacement of the differential manometer pen is recorded by a contactless method. For this purpose designer O. I. Shutov developed a photoelectric amplifier in which the luminous flux reacts with photocell type STsV-51 which is mounted under the panel of the tested differential manometer. A marker is attached to the differential manometer pen. The photoelectric current, which is proportional to the luminous flux incident on the photocell, and hence also proportional to the displacement of the pen, passes through a resistance providing a variable voltage drop fed to the grid of an amplifying tube which consists of one half of a double triode 6N1P.

The anode circuits of the photocell and tube 6N1P are supplied from the mains through a ferroresonant voltage stabilizer, a transformer and a full-wave rectifier. The second winding of the transformer supplies a full-wave rectifier which uses kenotron 6Ts5S. The voltage is smoothed by use of a Π-shaped filter and stabilized with an SG-4S stabilivolt. The load resistance (an oscillograph galvanometer type VIII) is connected to the cathode circuit. The final adjustment of the linear calibration characteristic of the pen displacement recording channel is provided by setting the position of the illuminator tube.

The equipment for obtaining frequency characteristics and the tested instrument constitute a single dynamic system, hence, the measurement error must be analyzed separately for each measured instrument.

One of the main dynamic parameters of the equipment proper consists of the operating frequency range of the harmonic pressure vibration generator. In order to determine this range the generator was connected to a 1 liter end chamber for the purpose of frequency testing, which showed that the non-uniformity in the generator's amplitude characteristic in the range up to 2 cps does not exceed 3%.

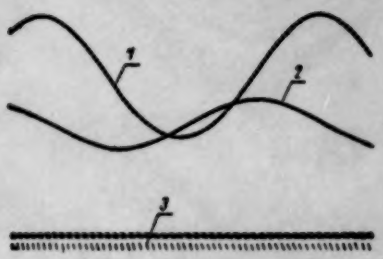

Fig. 3.

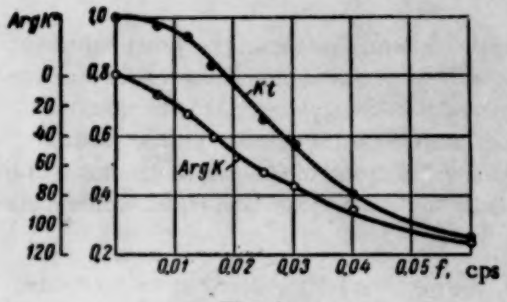

Fig. 4.

In order to determine the static error of the equipment, its recording channels were repeatedly calibrated (together with the tested instruments) by means of an oscillograph screen covered with a millimeter scale. The referred error thus obtained in measurements lasting 30 min (the maximum time normally used for frequency tests) did not exceed 3%.

In order to evaluate the shape of the pressure curve produced by the generator at a number of frequencies (0.05, 0.1, 0.5, and 1 cps) and amplitudes (5, 10, 15 and 25% of the tested manometer full-scale reading), the experimentally recorded curves were compared with sinusoidal calculated curves. This comparison showed that the deviation of experimental curves from the theoretical curves was within the accuracy of plotting.

The above equipment was used for testing recording instruments with circular charts consisting of a diaphragm differential manometer type DM-612 with a range of 0-100 mm Hg (with a device for extracting the square root) and a float differential manometer type DP-430 with a range of 0-40 mm Hg. Transfer characteristics for both instruments and frequency characteristics for differential manometer DP-430 were thus obtained.

In order to obtain the transfer characteristics, the positive chamber of the differential manometer was supplied with a pressure equal to the top measuring limit (the negative chamber was connected to the atmosphere). As soon as the instrument pen reached the upper reading on the chart, the rubber tube which supplied the pressure was disconnected. Since the input and output signals were recorded simultaneously there was no necessity for a special registration of the instant at which the tube was disconnected.

The differential manometer DM-612 transient characteristics thus produced on an oscillogram show the oscillations superposed on the basic curve (pen displacement). These oscillations are probably due to the fact that in the above instrument the pen is connected to the transmitting mechanism through a spring which introduces an additional degree of freedom into the measuring system.

In the frequency tests of the differential manometer DP-430, the harmonic pressure vibration generator was adjusted so as to obtain the constant component and oscillation amplitude equal to 50 and 25% of the differential manometer full-scale reading respectively. The oscillogram of the input and output signals taken at 0.042 cps is shown in Fig. 3, where 1 is the input signal (pressure), 2 is the output signal (pen displacement) and 3 is the time marker of 2 cps. Fig. 4 shows the experimental amplitude K and phase ArgK frequency characteristics of differential manometer DP-430 which were obtained from the oscillogram.

Conclusions. The above equipment and measurement technique make it possible to obtain dynamic characteristics of different recording differential and ordinary manometers, as well as of pressure transducers with a pneumatic output signal. For the latter purpose it is only necessary to use a second strain gauge, as described above, for recording the output signal and utilize the second channel of the TU-4M amplifier.

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ACOUSTICAL MEASUREMENTS

PROVISION OF UNIFORMITY IN SOUND PRESSURE MEASUREMENTS

A. N. Rivin

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Modern methods for testing electroacoustical instruments, for architectural-acoustical measurements, and for the measurement and spectral analysis of noise, are based on the application of measuring microphones which provide measurements of sound pressures in a free field with an error of 0.3-0.5 db. In order to provide uniform and correct measurements in the range from 20-30 cps to 16-20 kc stringent stability and calibration requirements are at present specified for measuring microphones.

Detailed research carried out in metrological laboratories of several countries has shown [1-5] that existing methods and equipment provide calibrations of measuring microphones with the required high accuracy (calibration of microphones in the small volume chamber, in a pipe resonator by means of a Rayleigh disc, and electrostatic calibration methods). Microphones calibrated by means of these methods provide measurements of sound pressure with an error not exceeding 0.2-0.3 db. This provides uniform measurements in testing telephones in the closed chamber of an "artificial ear" instrument, as well as in other tests which require the evaluation of the pressure on measuring microphone diaphragms.

The high precision calibration of measuring microphones cannot, however, be fully utilized in testing loudspeakers, microphones and other electroacoustical instruments, nor in measuring noise when it is necessary to evaluate sound pressure in the free field not distorted by the presence of a measuring microphone. The difference between the pressure acting on a microphone diaphragm and pressure in a free field is normally accounted for by introducing diffraction corrections which are equal to the field to pressure sensitivity ratio of the microphone expressed in decibels. The application of previously evaluated diffraction corrections eliminates direct free-space sensitivity measurements which involve considerable random errors, and thus provides uniform measurements of sound pressure in free space if the same type standard measuring microphones are used.

If measuring microphones of different types are used it is often impossible to attain uniform and accurate pressure measurements in free space, since the existing methods do not always provide diffraction corrections for microphones of different types with the required precision. The examples given below illustrate the existing state of these measurements.

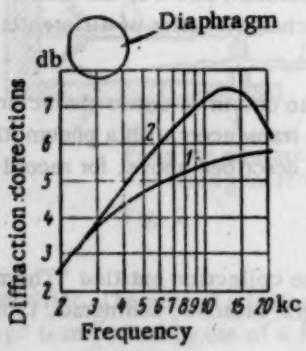

Fig. 1.

A reference measuring microphone type MEA-2 made by the LEA firm in France is calibrated by electrostatic methods on a special equipment. Its field sensitivity is determined with the application of diffraction corrections calculated by Ballantine [6] for a receiver of a regular spherical shape. The fact that the microphone has a flat diaphragm, thus distorting the regular spherical form and increasing the diffraction corrections, has not been taken into account. Fig. 1 shows the diffraction corrections for this microphone with the distortion of the form taken into consideration (curve 2) and without it (curve 1). The application of wrongly determined diffraction corrections in this instance leads to sound pressure measurement results systematically over-rated by amounts up to 1.5-2 db.

The measuring microphone type 4111 made by Brüel and Kjaer in Denmark is calibrated by the duality method in a small dimensions chamber, and by an absolute electrostatic method on a special apparatus type 4113. The field sensitivity is determined by means of diffraction corrections evaluated by calculating and measuring sound pressure in the center of the diaphragm. The uneven distribution of pressures over the diaphragm surface is not, however, taken into account. It is shown in Fig. 2 that the diffraction corrections thus obtained (curve 2) are

lower at high frequencies than their precise values (curve 1) by about 1.5 db, which leads to a corresponding systematic underestimation of sound pressure measurement results.

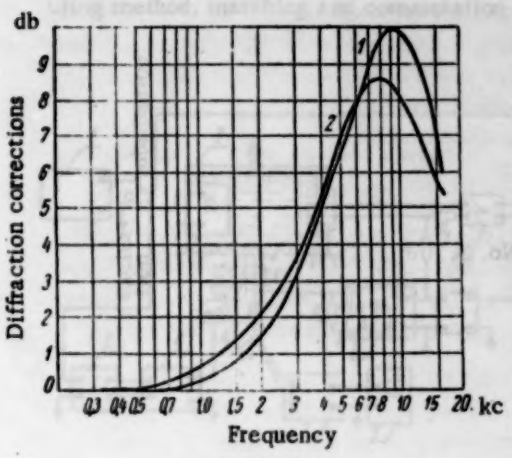

Fig. 2.

The above examples show that inaccuracies in determining diffraction corrections for microphones of various types may lead to considerable errors in measuring sound pressure in a free field. This makes a direct comparison of electroacoustical equipment measurements made in different countries difficult. It would be advisable in this connection to standardize the technique in determining diffraction corrections for measuring microphones of different types with the high precision required for ensuring uniformity of measurements. It is desirable that such a standard method should be formulated in the form of an international recommendation by the I.S.O.

The existing methods of determining diffraction corrections are based either on separate measurements of the field and pressure sensitivity of microphones [7] or on studying the distribution law of pressures on the microphone diaphragm placed in a free field of a plane travelling wave [7, 8]. These methods require a large number of measurements in a free field and do not provide diffraction corrections with the required accuracy. The method described by Spandock [9] requires fewer measurements in a free field; however, it entails absolute calibrations of the microphone for pressure and measurements of vibration velocities in various parts of the radiator diaphragm, which it is difficult to make with high precision. The graphic method for determining diffraction corrections described in [8] suffers from similar defects. According to this method the frequency characteristics of two microphones are first obtained electrostatically and then one microphone is used as a radiator in a free field, and the output voltage of the second microphone is automatically recorded (on a logarithmic scale). The frequency characteristic values of the microphones are then multiplied by the square of their frequencies and subtracted from the above voltages. These voltage levels are initially raised by a constant increment in order to obtain at low frequencies (where diffraction corrections are small) a difference equal to zero. For higher frequencies the above differences represent the diffraction corrections.

Previously [10] we have described a method for determining directly the diffraction coefficient by means of which it is possible to evaluate the diffraction correction by measuring the ratio of two voltages, and thus obtaining a more accurate evaluation than with the methods described above. The method is based on employing a sound radiator of the same type as the microphone. The radiator and the microphone are first placed in a free field at a short distance from each other, and later in a hydrogen-filled closed chamber of small dimensions. The voltage level variations across the microphone due to the transfer to the closed chamber are then observed with the current in the radiator circuit kept at a constant value. The voltage ratio E_f/E_c thus obtained is expressed in decibels and serves for calculating the diffraction correction by means of the relationship based on the electroacoustical theory of duality:

$$D=\frac{1}{2}\frac{E_f}{E_c}+10\lg\frac{c^2d}{f^2\pi V},$$

where d is the distance between the radiator and the receiver; V is the volume of the chamber; c is the speed of sound; f is the frequency.

This method is in good agreement with the standard method adopted by metrological laboratories of many countries for calibrating measuring microphones in a closed chamber of small dimensions. If in calibrating microphones and determining diffraction corrections chambers of the same dimensions are used, the errors in determining the acoustical resistance of chambers do not affect the accuracy of evaluating the field sensitivity of microphones. The tests carried out by us show that random and systematic errors in determining diffraction corrections by this method due to the nonuniformity of the sound field, the displacement of the acoustical center and other reasons do not exceed 0.2 db if measurements are carried out in a damped chamber.

Thus, it is possible to consider that diffraction corrections for measuring microphones of different types can be determined with an accuracy sufficient for providing uniform measurements of sound pressures in a free field.

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CALIBRATION OF MEASURING HYDROPHONES IN THE RANGE OF 0.1-100 cps

A. N. Golenkov

Translated from Izmeritel'naya Tekhnika, No. 9,
pp. 53-57, September, 1961

In hydroacoustical measurements it is customary to consider the infrasonic range as extending from fractions of a cps to 80-100 cps, although, strictly speaking, only frequencies below the threshold of audio sensitivity (up to 15-30 cps) should be included in this range.

The practical extension of the infrasonic range into the audio range is due to the calibration limits of hydrophones set by the closed chamber method. The acoustical impedance of such chambers for calibrating hydrophones can be considered as purely flexible up to the above audio frequencies (considerably lower than the first resonance of the entire system).

However, the requirement for determining accurately, in small closed chamber calibrations, the acoustical impedance of systems consisting of a chamber filled with water and hydroacoustical transducers normally complicates the calibration procedure, requires refined physical experimentation, and imposes stringent requirements on the acoustical conditions of measurements [1, 2].

In this article we describe an experimental equipment for calibrating hydrophones in the range of 0.1-100 cps by an electrodynamic compensation method developed by the All-Union Scientific Research Institute of Physico-technical and Radio-technical Measurements. The electrodynamic method of calibrating hydrophones [3]* makes it possible to avoid a direct determination of the system's acoustical impedance, and simplifies calibration.

The equipment was tested by means of piezoceramic transducers made to the specification of the Acoustical Institute of the USSR Academy of Sciences. Experience has shown that even thin (~ 2 mm) shells of the sensing elements in the shape of spheres or cylinders made of barium titanate ceramic (with the largest sizes amounting to 100 mm) are sufficiently rigid and have no natural resonance frequencies in the aforementioned audio-range. However, the high internal resistance of piezoceramic elements in the range of low infrasonic frequencies and their relatively small sensitivity require considerable amplification of small voltages and the use of the substitution method.

The difficulties are aggravated by the peculiarities of infrasonic measurements, which are affected by vibration interference arising in the structure of buildings and having a frequency and amplitude comparable with the measured signals. The difficulty in stabilizing the zero drift of amplifying circuits (at fractions of a cps) and the lack of effective infrasonic exciters further complicate the equipment operating at those frequencies.

* This method was used in [4] for calibrating hydroacoustical radiators.

The commercially produced infrasonic instruments have, as a rule, a low sensitivity for calibration purposes, an insufficient power and, unfortunately, they work badly with complex loads. However, a careful study of the measuring method, matching and commutation has made it possible to use these instruments in the test equipment.

In designing various units of this equipment special care was observed with respect to the mounting, screening and stabilizing of the supplies in order to reduce any external interference.

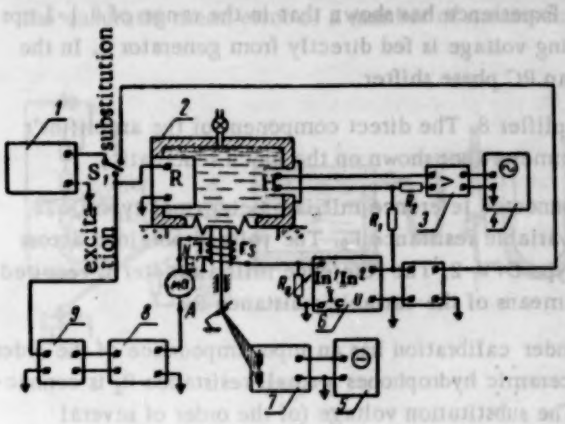

Fig. 1.

Method and equipment. The calibration technique described in [3] under the name of the zero balancing method of two vibrators was renamed by us as the electrodynamic compensation method, in order to stress its essence. The sound pressure exerted in the chamber was determined in this method by its direct compensation with an external electrodynamic force.

The compensation was attained on the diaphragm of an electrodynamic transducer which had a sensitive indicator of the diaphragm displacement. This indicator shows when the diaphragm becomes balanced-out under the simultaneous effect of the sound pressure in the chamber and the electrodynamic force directed toward the chamber. With such a compensation the acoustical impedance of the diaphragm approaches infinity. The compensation was attained by adjusting the phase and amplitude of current I_c in the coil of the electrodynamic transducer. The sound pressure p in the chamber can then be equated to the pressure produced by the electrodynamic force on a diaphragm with an area of S:

$$p = -\left(0.1\frac{BL}{S}\right) I_c = MI_c. \tag{1}$$

Relationship (1) does not depend on frequency, hence, the coefficient of proportionality M can be determined under a static condition and will depend only on the design of the electrodynamic transducer:

$$M = \frac{p_{st}}{I_0}, \tag{2}$$

where p_{st} is the known pressure set in the static calibration of the compensation transducer, and I_0 is the direct current flowing through the coil and required for compensating this pressure.

This method is convenient for extending the calibration range to the lowest frequencies.

Sensitivity E_x of the calibrated hydrophone is calculated from the formula

$$E_x = \frac{U_x}{I_c} \cdot \frac{I_0}{p_{st}} = \frac{1}{M} \cdot \frac{U_x}{I_c}, \tag{3}$$

where U_x is the output voltage of the calibrated hydrophone.

Thus, the calibration procedure in the above equipment is reduced to measuring the compensated output voltage of the hydrophone and the compensation current.

Since in calibrating piezoceramic hydrophones at low frequencies it is necessary to measure emfs of the order of several millivolts with an output transducer resistance of the order of tens of megohms, special devices had to be used in order to provide the required matching and switching of the equipment units. The block schematic of the equipment is shown in Fig. 1.

Measuring chamber 2 consists of a thick-walled cylindrical beaker with a hemispherical bottom made of BRAZh bronze. The minimum thickness of the beaker's side wall amounted to 30 mm, and of its bottom to 40 mm (in the center). The linear dimensions of the chamber's internal cavity do not exceed 400 mm. In order to excite infrasonic vibrations at relatively small sound pressures the chamber is fitted with a piezoelectric sound radiator R made of barium titanate ceramic and mounted on a hard lead packing. In order to reduce the effect of stray vibrations, measuring chamber 2 is mounted on brackets fixed to a main wall. Radiator R is coupled to generator 1 type NGPK-2 through a cathode follower (not shown on figure) which matches the load to the output of the generator. Electrodynamic trans-

ducer ET, which compensates sound pressure, is mounted in such a manner that the diaphragm forms part of the chamber's internal surface.

In order to adjust the compensation current both with respect to magnitude and phase the generator 1 output voltage is connected in the excitation position to phase shifter 9. Experience has shown that in the range of 0.1-1 cps it is not necessary to adjust the phase. In this case the compensating voltage is fed directly from generator 1. In the remaining range up to 100 cps the phase is adjusted by means of an RC phase shifter.

The output voltage of the phase shifter is fed to current amplifier 8. The direct component of the amplifier's output current should equal zero, which is indicated on a microammeter (not shown on the block schematic).

The load between point A and ground consists of a series-connected reference milliammeter (ma) type D528, the coil of the electrodynamic transducer ET, and a nonreactive variable resistance R_6. The voltage obtained across this resistance is fed to input In. 1 of a double peak voltmeter 6 type DPV-2. The reference milliammeter is required for calibrating the pointer instrument of voltmeter 6 at 50 cps by means of the variable resistance R_6.

The ac preamplifier 3 in the output line of hydrophone H under calibration has an input impedance of the order of 11 meg. Since a substitution method has to be used with piezoceramic hydrophones a small resistance R_2 is connected in the negative (ungrounded) output lead of the hydrophone. The substitution voltage (of the order of several millivolts) is measured on voltmeter 6 through a calibrated potential divider R_1 and R_2 with a voltage ratio $K = 1/1000$. The input voltage of the potential divider was adjusted with the help of oscilloscope 4 type ÉNO-1 (switch S_1 in the "Substitution" position). The peak value U of this voltage was measured on voltmeter DPV-2.

The substitution voltage U_X was determined from the formula

$$U_x = \frac{U}{1000}. \qquad (4)$$

The combination of the electrodynamic system with a device for indicating the stationary condition of the diaphragm (compensation) determines the design of the compensation transducer, which is the main unit of the equipment.

The compensation transducer comprises a normal electrodynamic system with a ring magnet. The induction in the gap amounts to ~ 8000 gauss. The transducer's coil has a resistance of 16 ohm and is mounted in the thicker middle portion of the diaphragm. The flat diaphragm consists of a collar 130 mm in diameter and 0.6 mm thick left on the cylindrically turned body of the electrodynamic transducer. The diaphragm thickness was chosen experimentally in such a manner as to make the natural frequency of the whole compensation transducer considerably higher than the operating range (~ 1000 cps).

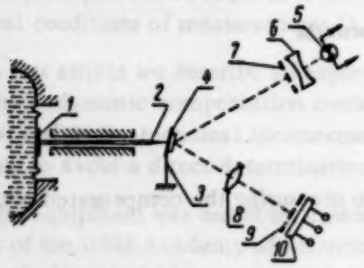

Fig. 2. 1) Diaphragm; 2) rod; 3) phosphor-bronze spring; 4) mirrer; 5) illuminating lamp supplied from a storage battery; 6) condenser; 7) lens diaphragm; 8) objective; 9) mask; 10) photovaristor. The photoamplifier unit is enclosed in a jacket.

The electrodynamic compensation equipment comprises a photoamplifying device based on the use of photovaristors. In order to raise the sensitivity of the photovaristor it is covered with an opaque mask with several openings in it (according to the number of slits in the diaphragm).

The optical schematic of the photoindicator is shown in Fig. 2. By means of an electrical circuit variations in resistance are transformed into voltage changes. Balancing is observed visually when the signal shape is changed to a straight line on the screen of oscilloscope 5 type ÉNO-1 (see Fig. 1), which is connected to the output of photoamplifier 7.

In order to exercise control in measuring constant M of the compensation transducer, the equipment is provided with a special device. By means of this device it is possible to set and measure the relative variation of static pressure in the chamber. A facility is provided in the compensation channel for converting a dc signal due to a static displacement of the diaphragm into an ac signal. In this case balancing is also indicated on the screen of oscilloscope 5 by the disappearance of a pulse train whose amplitude is proportional to the constant deflection of the diaphragm from its original position.

An instrument of A. I. Petrov's system [5] was used for setting and measuring the static pressure. This instrument's beaker is connected to the measuring chamber. The relative variation of the hydrostatic column of water in the beaker was measured on the scale of a micrometer screw which set the displacement of the needle. In this case the quadratic mean error of a number of measurements of M amounted to ~ 8%.

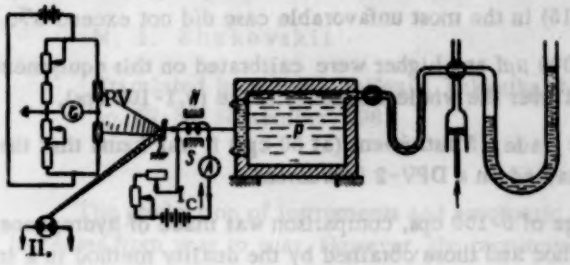

Fig. 3.

Static calibration of the compensation transducer. The relation between the compensation current and static pressure was first studied, and it was found that it is linear in the pressure range of 1-8 cm of water (980-7600 d/cm^2). The coefficient of proportionality $M = p_{st}/I_0$ was found experimentally.

Despite the fact that the measurements of M were not made at pressures below 980 d/cm^2, the linear relationship can be approximately extended to zero, since the origin of coordinates p_{st} and I_0 is determined by the initial static pressure in the chamber.

The value of M was found to be equal to 32.8 d/cm^2/ma with the quadratic mean error of a number of measurements being under 2%. A prolonged use of the equipment showed that M remains practically constant in the range of room temperatures.

The relative variation of static pressure in the measuring chamber was measured on a U-shaped manometer. The photovaristors were connected in a bridge circuit, in which the other two arms consisted of resistance boxes type KSM-6.

The bridge was balanced for the initial hydrostatic pressure. The static pressure was then changed by means of rheostats which were connected in series with the winding of an electrodynamic transducer, and the direct current required to restore balance (as observed on galvanometer G) was measured. This current was measured on a grade 0.2 reference milliammeter (ma). The sensitivity of the photoindicator in these measurements amounted to 0.003 μa/d/cm^2. It was found difficult to obtain a higher sensitivity owing to the galvanometer's zero drift.

The sound pressure in the chamber due to the compensation of the diaphragm movement reached 2.5 db.

The sensitivity of the compensation channel was determined directly by sound pressure instead of the displacement of the diaphragm. A given constant sound pressure was maintained in the chamber by means of a hydrophone whose sensitivity in the given frequency range was constant and known in advance. It is also possible to set the compensation current and thus maintain a constant sound pressure in the chamber.

The peak output voltage was measured in the channel on the scale of oscilloscope 5 (Fig. 1), which was calibrated in advance with an error of less than 10%. The frequency characteristic has, according to expectations, a downward slope at higher frequencies, due mainly to a rise in the reactance of the transducer diaphragm. The smallest sensitivity was obtained at the upper limit of the range (100 cps) and amounted to the peak value of 4.1 mv/d/cm^2. The drop of the characteristic at low frequencies is due to the insufficiently large time constant of the photoamplifier.

In order to determine the dynamic range of a plane diaphragm oscillation, the sound pressure in the chamber was raised by means of an air and water resonator [2] (at 4 cps) up to ~ 2000 d/cm^2. No distortion in the oscillations under these conditions was observed. Neither were there any noticeable variations in the compensation current when the hydrostatic pressure on the diaphragm was raised up to ~ 50000 d/cm^2. The normal hydrostatic pressure in the chamber during calibrations amounted to ~ 15000 d/cm^2.

In order to check the uniformity of the sound pressure distribution in the measuring chamber, the hydrophones were calibrated in various parts of the chamber. Experience has shown that the non-uniformity of sound pressure distribution in the chamber may amount to 0.4 db for free oscillations of the diaphragm. With compensation the sound pressure becomes virtually uniform throughout the chamber. The measured sensitivity of hydrophones was constant irrespective of their position in the chamber. However, it was noted at 100 cps that hydrophones placed close to the diaphragm (5-10 mm) had a slightly higher (up to 10%) compensation current, and their calibration measurements became dispersed.

Evaluating the accuracy of hydrophone calibrations. The sensitivity (E_x) of hydrophones calibrated on the above equipment is calculated from formula (3) which, amended by the value of M = 32.8 d/cm^2/ma, the voltage ratio of the potential divider and factor 1.41, assumes for a peak voltage the following form:

$$E_x = 21.7 \frac{U}{I_c} \frac{\mu v}{d/cm^2}. \quad (5)$$

Here U is expressed in peak volts, I_c in milliamperes, and factor 21.7 is a constant parameter of the equipment.

The reproducibility of value U/I_c was studied under various calibration conditions of hydrophones. The quadratic mean error of a number of measurements (not less than 15) in the most unfavorable case did not exceed 3%.

Several piezoceramic hydrophones of a capacity of 8000 μμf and higher were calibrated on this equipment. Their sensitivity-frequency characteristic remained constant over the whole frequency range (0.1-100 cps).

By measuring I_c and U on a reference electrodynamic grade 0.5 instrument (at 50 cps) it was found that the sensitivity of hydrophones was about 2% higher than that obtained on a DPV-2 instrument.

In order to eliminate any systematic errors in the range of 5-100 cps, comparison was made of hydrophone calibrations obtained by the electromagnetic compensation method and those obtained by the duality method in a small water-filled chamber [2]. The discrepancy in the mean sensitivity values obtained by either method amounted to 0.5 db, i.e. it was within the tolerance of either method. Random errors in calibrating hydrophones are mainly due to the limited accuracy of DPV-2 voltmeters, which are used for measuring the output voltage of the hydrophones and the compensation current of the electrodynamic transducer.

Questions of measurement techniques were studied with the participation of I. G. Rusakov. Engineer S. G. Golub' took part in the experiments.

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All abbreviations of periodicals in the above bibliography are letter-by-letter transliterations of the abbreviations as given in the original Russian journal. *Some or all of this periodical literature may well be available in English translation.* A complete list of the cover-to-cover English translations appears at the back of this issue.

MATERIAL RECEIVED BY THE EDITORIAL BOARD

IMPLEMENTING THE DECISION OF THE 1st ALL-UNION CONFERENCE ON ELASTIC SENSITIVE ELEMENTS

N. I. Zhukovskii

Translated from Izmeritel'naya Tekhnika, No. 9,
pp. 57-58, September, 1961

The production of instruments and automatic regulators for checking and controlling thermal power processes increases from year to year. However, the requirements of our national economy are not fully satisfied, since these requirements are due not only to wide automation of thermal processes, but mainly to the extremely short life of instruments (8-12 months) resulting from the low quality of their sensitive elements. Production capacities wastefully engaged in replacing instruments which fail prematurely amount to several instrument-making plants.

Large funds are spent on repairs. Thus, over 1 million rubles is spent annually on premature repairs of commercial manometers made by the Tomsk manometer plant. Moreover after major repairs instruments normally lose their calibration. If the sensing element fails completely (owing to damage, corrosion, etc.) the instrument has to be discarded, since in the majority of cases the replacement of sensing elements can only be made at the manufacturing plant. The failure of an instrument, defects in its accuracy or in the adjustment of the automatic regulator, which forms part of the automation system, lead to disruption or instability of production processes, especially in key branches of our industry such as metallurgy, the chemical and oil industries, etc.

The low quality of elastic sensing elements is due to the low level of their scientific and technical development and design, as well as to the low development of rational technological processes in this sphere. The work to improve reliability of sensing elements is conducted independently by various organizations, without any coordination, and often in a makeshift manner. No scientific methods for computing sensing elements exist, which leads to the selection of design parameters in a haphazard manner, often without regard to the operation conditions. Experimental facilities for carrying out the scientific research work are inadequate.

The choice of sensing element materials on which depends the stability of operation is extremely limited. The precision alloys made by our metallurgical plants do not meet modern operation requirements of the instruments, especially with respect to their operation in corrosive media and at high temperatures. Research for new alloys and their use in production is proceeding very slowly.

The production of semi-finished articles for sensing elements (seamless welded pipes for tube springs and bellows, strips for diaphragms, etc.) is relegated in metallurgical plants to a secondary place owing to its small volume (tonnage) compared with the total output of plants. As a result of this the dimensions, mechanical and physical properties of semi-finished articles are unsuitable for making high-quality sensing elements.

Flexible and elastic sensing elements have not, as yet been unified, normalized or standardized. Thus, no data exist for specialized production. Each instrument-making plant organizes the production of sensing elements for its own use in nonspecialized equipment, which leads to makeshift production with a large proportion of manual labor and results in the low quality of the product. The basic production operation (bending, heat treatment, aging and stabilization) is carried out at various plants according to different techniques.

Approved equipment and methods for an objective testing of the quality of elastic sensing elements produced by various organizations are almost completely lacking.

A radical improvement in the quality of sensing elements can only be achieved at the cost of a considerable extension of theoretical, design and experimental work coordinated from a single center.

In March, 1960, the State Scientific and Technical Committee of the RSFSR Council of Ministers in conjunction with the Committee for Automation and Engineering held an All-Union Scientific and Technical Conference on elastic sensing elements used in instruments and automation equipment.

The conference was attended by more than 500 representatives of plants, special design offices and scientific research institutes. The conference passed a resolution on the urgent necessity for measures to eliminate lagging in the design, technology and production of sensing elements.

The same conference worked out and adopted several recommendations for extending scientific research and experimental design work in standardizing and normalizing the development of technological processes, methods of checking and organizational measures for improving the production of sensing elements. For instance, the conference recommended the establishment of special design and technological bureaus for elastic sensing elements (attached to the scientific research institute of thermal instrument making), the issuing of the conference proceedings and the papers read at the conference, etc. However, despite the fact that over a year has passed since these resolutions were adopted, the recommendations of the All-Union Conference are not being fulfilled.

The Committee for Automation and Engineering must take immediate steps to implement the decisions of the All-Union Conference on elastic sensing elements.

EXPERIENCE IN THE WORK OF THE GKLs (STATE INSPECTION LABORATORIES) IN ASSISTING THE ASSIMILATION OF NEW MEASUREMENT EQUIPMENT BY OUR NATIONAL ECONOMY

I. I. Kogan

Translated from Izmeritel'naya Tekhnika, No. 9,
pp. 58-60, September, 1961

The task of introducing integrated mechanization and automation of production processes on a wide scale in all branches of our national economy requires the production and application of new and improved testing and measuring instruments, regulating devices, computing and controlling machines, testing mechanisms, and automatic batching equipment.

In many regions and territories of the Russian Federation the state inspection laboratories for measuring equipment (GKLs) act as good organizers in introducing into our national economy new measuring equipment, and conduct in this respect extensive work.

The Chelyabinsk GKL, for instance, insisted on the development of long-term plans for introducing measuring equipment in 1960-65 at 53 of the largest plants in the region; similar plans have been compiled for different industrial administrations of theSovnarkhoz (Council of National Economy).

The plans envisage over 2000 measures, the majority of which are related to production automation and raising the accuracy of measurements. Thus, the ChT plant has guaranteed the introduction of 150 new instruments of various types; the zinc plant, 50 instruments for automatic checking of thermal processes; the Kyshtym electrolytic copper plant will introduce 12 instruments for automatic control of the electrolytic shop production, etc.

At the initiative of the GKL, seminars were held at the end of 1960 for workers in factory laboratories and administrators of Chelyabinsk regional establishments on problems of electrical measurements.

The seminars were also attended by representatives from factory laboratories of the Bashkir, Sverdlovsk, Perm', Kurgan and Orenburg regions. A special seminar was held for workers of the control and measuring instruments and the automation workshops, on problems of introducing new measuring equipment and automation of thermal processes.

The personnel of the Kostroma GKL assisted in introducing instruments for automatic checking of the parameters of open-hearth processes in the "Strommashina" and "Rabochii metallist" Plants and automatic heat control of boilers and power installations in the local electric power station. As a result of combined work of the factory

laboratory and the GKL, automatic control of two open hearth furnaces and two annealing ovens was introduced at the "Strommashina" Plant, which improved the quality of steel smelting, halved the amount of rejects, raised productivity, improved working conditions, and provided the plant with a considerable saving.

In supporting the initiative of the GKL the Kostroma Sovnarkhoz adopted the necessary measures for supplying the above plants with the required equipment and measuring instruments, and the GKL assisted these plants in introducing 25 new instruments of the latest types. The satisfactory results obtained at these plants have made it possible to exchange experience gained in this respect with other chief engineers, technologists, factory test laboratory and Sovnarkhoz personnel, and to adopt a recommendation for providing automatic control of open-hearth furnaces in other plants.

The work of the Kostroma GKL in assisting integrated mechanization and automation is not restricted to engineering plants. At the suggestion of the GKL the regional administration of bakeries has installed in certain of its organizations automatic and semi-automatic scales which perform the functions of sorting, weighing and packing. Such automation has also produced advantageous results.

Having studied thoroughly the condition of measuring equipment at the plants, the GKL makes recommendations to the Sovnarkhoz for better and more rational utilization of measuring instruments, including their transfer from one plant to another. Thus, at the suggestion of the GKL, four sets of tungsten-molybdenum thermocouples were transferred from the excavator plant to the "Strommashina" Plant where they are being used to measure the temperature of steel.

In this sphere experience has also been accumulated by the Gor'kii GKL. On the initiative of the GKL the Gor'kii Automobile Plant has checked on a wide scale the automation and mechanization of testing. Experts from the Sovnarkhoz and other plants participated in this work. The results of this investigation were discussed at a session of the technical and economic council of the Sovnarkhoz, and appropriate measures were adopted for a further extension of statistical methods of testing, which eliminate rejects and save labor time, for establishing rigid production methods, for a further mechanization of testing, etc. At present a special centralized service has been set up in the plant for introducing new automatic testing equipment, and supervising its operation and repair. In a short time this service has introduced automatic testing instruments in 12 production processes.

As a result of the work carried out by the Orenburg GKL the South Ural engineering plant has introduced complete automatic control in 5 thermal ovens which use 10 centrifugal regulators and 15 potentiometers. Automatic control has also been installed in two open hearth furnaces where 6 potentiometers are being used. These measures have produced a saving of 10% in the generator gas, of a large quantity of refractory materials and crude oil, in addition to improving the steel smelters' working conditions.

The Ivanovo GKL discovered an infringement of the technological process of drying cloth at the Teikovo cotton textiles plant. The drying was not checked by any instruments at all and the cloth emerged from the process in an undried state. The GKL recommended the installation of recording manometric thermometers type TG-610, remote recording thermometers and automatic machines for controlling the temperature in allied processes. The GKL's recommendation was adopted and put into practice.

The experience of the Krasnoyarsk GKL is also instructive. It helped one of the plants to improve its galvanizing process by recommending the installation of an automatic regulator of current density, which included a time relay. As a result of applying this recommendation the rejects were reduced to less than one-half. At another plant, at the suggestion of the GKL, mercury manometric thermometers were replaced by platinum resistance thermometers with a switching device connecting them to a single ratiometer which provided a control of the process by a single operator from a control desk. As a result of this the accuracy of temperature measurements was raised, the production quality improved, labor productivity increased and a considerable saving obtained.

On the GKL's recommendation automatic batching machines were installed at the concrete plant for weighing out gravel, cement and water, thus providing an accurate mixture, improving the quality of concrete and raising labor productivity.

At the initiative of the Kalinin GKL a regional conference of factory laboratory personnel was held, with the participation of representatives from the Sovnarkhoz and other organizations.

At the conference a number of delegates described their experience in developing automatic equipment for controlling technological processes, ensuring uniformity, accuracy and efficiency in applying gauges and measuring

instruments, as well as enhancing the part played by the central factory laboratory in the technical progress of their plant.

On the basis of the decisions of this conference the Sovnarkhoz issued an instruction on March 15, 1961, on "Measures for improving the operation of factory laboratories and enhancing the part they play in the technical progress of plants in their economic region;" it also approved and put into operation a "Regulation on area laboratories in the Kalinin Sovnarkhoz". The Sovnarkhoz instructed plants to amend the previously submitted 7-year plans for introducing new measuring equipment, to increase the laboratories' trained personnel, organize technical instruction and training for laboratory workers at other plants.

The personnel of the Udmurt GKL devote much energy and time to improving production processes at the largest plants of the Republic.

At the suggestion of the GKL the Izhevsk metallurgical plant has introduced electronic potentiometers for checking thermal processes in cooling wells and electronic type ÉR-IIIK regulators for controlling automatically the burning of fuel in boilers, thus providing a stable burning process and saving in fuel.

The Votkino Plant has introduced smoke density indicators based on semiconductor photocells, thus improving fuel combustion. Following a recommendation by the GKL, the Udmurt Sovnarkhoz has installed instruments for automatically controlling the drying of timber.

The inspection laboratories of the Russian Federation cooperate in their work of supervising and assisting the adoption of automatic equipment for controlling the quality of production and of technological processes with scientific research institutes and design offices, and render them the necessary assistance. For instance, the newly organized Stalingrad scientific research institute has received practical assistance in the choice of its measuring equipment related to the development of new technology which is being introduced in engineering plants, and in organizing new test laboratories of the institute with respect to equipping them with measuring instruments of a quality up to the level of modern requirements.

At the request of the Voronezh experimental scientific research institute of forge and press engineering the Voronezh GKL calibrated its strain gauge crane scales for weighing large details, which were designed by the institute for the Kalinin Voronezh plant.

The Altai GKL has helped the automation design office in organizing a scientific research laboratory for thermal control and electrical measuring instruments.

The GKLs have also carried out other work in introducing new measurement equipment in the plants of the Russian Federation.

The Administration of the Representative of the Committee of Standards, Measures and Measuring Instruments attached to the RSFSR Council of Ministers has summarized the activity of the GKLs in assisting the assimilation by our national economy of improved measuring equipment in 1960. It considers the operation of many GKLs as satisfactory. The Administration has outlined further ways of accelerating the installation of new measuring equipment, and has recommended for this purpose that plans be developed for its assimilation, beginning with an analysis of the extent to which production processes are served by modern control instruments, with the effective assignment of gauges and measuring instruments, as well as methods, which should be up to the level of modern requirements, and with relating the quality of production to the efficiency of production measurements.

The Administration recommends that the above work should be carried out by commissions consisting of representatives from plants and their superior organizations with the direct participation of the GKLs.

The work of these technological commissions should form the basis for compiling and amending plans originated by plants for introducing new measuring equipment. It is very important that the commissions' work should be used by as many interested industrial plants as possible.

The organizational work of the GKLs is in this respect of great importance.

These and other methods recommended by the Administration for organizing the work of the GKLs are aimed at attaining more effective results in introducing new measuring equipment in the national economy of the RSFSR.

INFORMATION

THE 2nd CONGRESS OF THE INTERNATIONAL AUTOMATIC CONTROL FEDERATION

V. A. Trapeznikov (Chairman of the USSR National Committee for Automatic Control)

Translated from Izmeritel'naya Tekhnika, No. 9,
p. 61, September, 1961

In March 1961 the Executive Council of the International Automatic Control Federation (IACF) at its meeting under the chairmanship of the President of the Federation, Prof. A. M. Letov, decided to hold the 2nd International Congress of the IACF on automatic control at Basle in September 1963 with an agenda which includes the following points:

1. Theory of automatic control: discrete system, stochastic processes, optimal system, self-adjusting systems, theory of reliability.

2. Application of automatic control: investigating the dynamics of processes, study of industrial automation problems by means of digital and analog computers included in or excluded from the process, application of optimizing and self-adjusting control systems.

3. Components: new and efficient devices, evaluating the reliability of components.

4. Other subjects: education, terminology, bibliography.

This agenda does not exclude other topics, but at least 80% of all the papers should be on theory and application, and not more than 20% on components and other subjects.

The toal number of approved papers must not exceed 100.

The selection of papers will be entrusted to the national committees of the IACF. The papers of Soviet contributors should be submitted to the National Committee of the Soviet Union on Automatic Control (Moscow, I-53, Kalanchevskaya Street, No. 15a) not later than December 31, 1961. Each paper must not exceed 30000 printed characters, including a resume not exceeding 200 words in Russian and in English and illustrations.

The final selection of papers will be made by the contributions' committee of the IACF.

OBITUARY

M. S. ZHAVORONKOV

Translated from Izmeritel'naya Tekhnika, No. 9,
p. 61, September, 1961

On July 25, 1961, Mikhail Semyonovich Zhavoronkov, one of the oldest collaborators of the metrological service of our country, died after a long and grave illness.

M. S. Zhavoronkov was born on November 7, 1883 in the Gor'kii region. Having started work in 1900 Mikhail Semyonovich was admitted in 1903 to the Weights and Measures Chamber in the town of Pavlovo on the Oka, and from then onwards dedicated the whole of his working life to the state service of measures and measuring instruments.

Having risen from a state inspector to a head of a laboratory and senior engineer of the Committee of Standards, Measures and Measuring Instruments, Mikhail Semyonovich became one of the leading experts on weighing instruments.

M. S. Zhavoronkov produced several original designs for scales, and in particular scales with elastic (band) supports and semi-automatic scales for checking milligram weights.

M. S. Zhavoronkov compiled several instructions on checking weighing instruments, and wrote many papers on weighing instruments.

In 1938 Mikhail Semyonovich participated in compiling a monograph on "Scales", and in 1950 a textbook on "Weighing Instruments", which remains one of the basic textbooks for training experts on weighing instruments, not only in the USSR but also in the Chinese People's Republic (the textbook on "Weighing Instruments" has been translated into Chinese).

In 1954 Mikhail Semyonovich wrote in co-operation with Candidate of Technical Sciencies D. S. Dubov a book on "Elastic Supports for Weighing Instruments".

M. S. Zhavoronkov wrote several articles on scales published in the periodic press and in the Great Soviet Encyclopedia.

Mikhail Semyonovich was also engaged in many educational activities. He trained many state inspectors and experts on weighing instruments for many branches of our national economy.

For his successful work M. S. Zhavoronkov was awarded medals of the Soviet Union and the badge of "Outstanding metrologist."

Soviet metrology has lost in the person of M. S. Zhavoronkov a gifted expert.

His pupils and comrades will always keep in their hearts the cherished memory of their teacher and friend.

FROM FOREIGN JOURNALS

FEINGERÄTETECHNIK

1961, No. 6

R. Lehmann and others. High sensitivity precision indicator based on an induction transducer. Description of an instrument with a differential induction transducer for measuring linear dimensions (lengths, surface roughness, elongation, etc.).

H. Schwieger. Optical polarization instrument for measuring under reflected light internal stresses in articles.

G. Weinhold. Measurement of spur wheels by means of balls. Part 3. Examples are given of their application and computations in measuring spur wheels with external and internal gearing.

H. Kortum. Determining the concepts of mechanization and automation. Definitions of the above concepts are recommended, schemes for mechanization and automation processes are given. The definitions of these concepts in various countries are examined.

K. Schuch. Automation equipment shown at two Italian exhibitions during 1960. A brief description is given of the exhibits shown at the two Italian engineering and instrument-making exhibitions in Turin and Milan in September and October, 1960.

INSTRUMENTS AND CONTROL SYSTEMS

1961, No. 2

D. Newhall and L. Abbot. A new manometer design for measuring high pressures from 3500 to 14000 kg-wt/cm^2 with a bulk-elastic element.

H. Seegers. Review of the latest designs of bourdon tubes, of materials for their construction, their practical application and methods for their testing, in particular the technique of setting the zero point in repeated tests.

V. Buffenmeyer. Selection of elastic elements of the bourdon type tubes in manometers used for various purposes.

G. Norton. Potentiometric pressure transducers. Certain types of pressure transducers with an electrical output signal are reviewed.

L. Moskowitz. Calibration of accelerometers. Part 1. Measurement of a given acceleration. The calibration accuracies are examined for the case of a free drop, a rotary motion, a constant and periodic angular acceleration, as well as for impulse and sinusoidal vibrators.

1961, No. 3

M. Laikin. Optical systems. Lenses, mirrors, spherical surfaces and planes are analyzed. Various factors are also discussed, such as the type of glass, flaws, annealing, etching and surface quality, which greatly affect the design of optical systems.

L. Moskowitz. Calibration of accelerometers. Part 2. Measuring the output signal of accelerometers and determining their sensitivity with the waveform taken into consideration.

Reference and commercial electrical measuring instruments. Reference and commercial measuring instruments are enumerated and briefly described, their testing periods are indicated, the required test laboratory equipment is listed.

A new test laboratory. A description is given of the equipment of the new test laboratory "Metrolonics", which serves as an auxiliary link between the National Bureau of Standards and the users of precision instruments who submit for testing.

1961, No. 1

J. Hunter. Level indicator and timer for measuring tanks. A description is given of a simple and accurate optical device for indicating the liquid level. The device is based on measuring the refraction index of liquids. The error is of the order of 0.25 mm.

1961, No. 2

A signal generator test rack. A description is provided of a test rack designed by the National Bureau of Standards (USA) for testing signal generators with output signals of 1 to 100000 μv in the range of 30 kc to 40 Mc. The measurement error is between 2 and 5%, depending on the frequency.

1961, No. 3

Effect of humidity on analytical balances. Report on investigations carried out by the National Bureau of Standards (USA) on errors in analytical balances, produced by variations in the relative humidity, and on the possibility of eliminating them.

1961, No. 4

Calibration of thermocouples. Report on the calibration of thermocouples in the range of −190 to + 1100°C carried out by the National Bureau of Standards. Three calibration methods are described: by comparison with reference resistance thermometers; by comparison with reference platinum-rhodium thermocouples; or against the reference points of the International Temperature Scale.

A. Pande. Design of an electronic hygrometer for measuring moisture content in textiles and other hygroscopic materials, developed by the Institute of Industrial Research in Delhi (India).

R. West. Review of constricting devices which serve to measure the rate of flow. Theoretical questions pertaining to rate of flow measurements are discussed, and a number of designs for diaphragms and devices of the Venturi tube type are provided.

COMMITTEE OF STANDARDS, MEASURES AND MEASURING INSTRUMENTS

I. NEW SPECIFICATIONS FOR MEASURES AND MEASURING INSTRUMENTS, APPROVED BY THE COMMITTEE

New Standards (Registered in July, 1961)

GOST (All-Union State Standard) 6933-61. Spring-loaded measuring heads. Mikrokators. Replacing GOST 6933-54. Effective from July 1, 1962.

GOST 8550-61. Thermal units. Replacing GOST 8550-57 and OST VKS 6954. Effective from July 1, 1962.

GOST 9829-61. Light-beam oscillographs. General technical requirements. First issue. Effective from July 1, 1962.

Cancelled Standards

OST 20102. Extensometers. Basic parameters and technical conditions. Cancelled from July 1, 1962.

New Instructions on Testing Measures and Measuring Instruments

Instruction 131-61 for testing commercial levels. Replacing instruction 131-57. Effective from February 1, 1962.

Instruction 167-61 for testing commercial optical pyrometers with a vanishing filament. Replacing instruction 167-54. Effective from January 1, 1962.

Instruction 239-61 for checking compression and bending test machines for building materials. Effective from January 1, 1962.

Instruction 248-61 for testing millisecond timers. Effective from January, 1962.

II. OPERATING INSTRUCTIONS ISSUED FOR CHECKING MEASURES AND MEASURING INSTRUMENTS AND APPROVED BY THE COMMITTEE'S MEASURING INSTRUMENTS ADMINISTRATION

Operating instruction No. 182 for checking diamond cone tips of Rockwell commercial hardness testing instruments. Effective from January 1, 1962.

Operating instruction No. 183 for checking diamond pyramid tips of Vickers commercial hardness testing instruments. Effective from January 1, 1962.

III. MEASURES AND MEASURING INSTRUMENTS APPROVED BY THE COMMITTEE AS THE RESULT OF STATE TESTING AND PASSED FOR USE IN THE USSR

(Registered in June and July, 1961)

Million-megohm meters, trade mark MOM-4 of the Estonian Sovnarkhoz (Council of National Economy). State Register No. 1473-61.

Continuously variable attenuators for the decimeter range, trade mark PA, of the Leningrad Sovnarkhoz. State Register No. 1474-61.

Mikrokators, trade mark PKM, of the Novosibirsk Sovnarkhoz. State Register No. 1475-61.

Hydraulic presses, trade mark 2PG-10, 2PG-50, 2PG-125, 2PG-250 and 2PG-500, of the Krasnodar Sovnarkhoz. State Register No. 1476-61.

Refractometers, trade mark RDU, of the Kiev Sovnarkhoz. State Register No. 1477-61.

Counting scales, trade mark SCh-500(b) of the Krasnodar Sovnarkhoz. State Register No. 1478-61.

Diaphragm, pneumatic, compensation, differential manometers, trade mark DMPK-100, of the Moscow City Sovnarkhoz. State Register No. 1479-61.

Automatic machines for measuring-out and sale of aerated water, trade mark AT-114, of the RSFSR Ministry of Trade. State Register No. 1480-61.

Portable wattmeters, trade mark D381, of the Krasnodar Sovnarkhoz. State register No. 1481-61.

Portable phase meters, trade mark D382, of the Krasnodar Sovnarkhoz. State Register No. 1482-61.

Portable recording ammeters, voltmeters and voltammeters, trade mark N387 of the Krasnodar Sovnarkhoz. State Register No. 1483-61.

Rack-mounted ammeters and voltmeters, trade mark É301 of the Krasnodar Sovnarkhoz. State Register No. 1484-61.

Rack-mounted ammeters and voltmeters, trade mark É302, of the Krasnodar Sovnarkhoz. State Register No. 1485-61.

Thermocouple portable ammeters, trade mark T18, of the Leningrad Sovnarkhoz. State Register No. 1486-61.

Audio oscillators, trade mark ZG-14 (GZ-18) of the Leningrad Sovnarkhoz. State Register No. 1488-61.

Cathetometers, trade mark KM-6, of the Leningrad Sovnarkhoz, State Register No. 1489-61.

Interferometers for liquids and gases, trade mark ITR-1, of the Moscow Regional Sovnarkhoz. State Register No. 1490-61.

Traction gauges, trade mark TM-P1, thrust gauges, trade mark NM-P1, and traction and thrust gauges, trade mark TNM-P1, of the Moscow City Sovnarkhoz. State Register No. 1491-61.

Rack-mounted microammeter, trade mark M97, of the Armenian Sovnarkhoz. State Register No. 1492-61.

Device for measuring large direct currents up to 70 ka, trade mark I58, of the Kiev Sovnarkhoz. State Register No. 1493-61.

Measuring attenuators, trade mark AVP-121 of the State Committee for Radioelectronics of the USSR Council of Ministers. State Register No. 1495-61.

Triple-web table. Trade mark IP-5 for a vertical optimeter IKV, of the Leningrad Sovnarkhoz. State Register No. 1496-61.

High-resistance indicating converter, trade mark PVU-5256, of the Leningrad Sovnarkhoz. State Register No. 1497-61.

Thermal meters, trade mark TS-1, of the Estonian Sovnarkhoz. State Register No. 1498-61.

Diaphragm pneumatic compensation differential manometers, trade mark DMPK-4, of the Moscow City Sovnarkhoz. State Register No. 1499-61.

Rack-mounted interchangeable calibrated multiplier resistors, trade mark R103, of the Krasnodar Sovnarkhoz. State Register No. 1501-61.

Portable megohmmeter, trade mark MOMP-1, of the Byelorussian Sovnarkhoz. State Register No. 1502-61.

Measuring lines, trade mark LI-4, of the Leningrad Sovnarkhoz. State Register No. 1503-61.

Current transformers, trade mark I55/1, of the Cherkassy Sovnarkhoz. State Register No. 1504-61.

Low-frequency Q-meter, trade mark IDN-1, of the Leningrad Sovnarkhoz. State Register No. 1505-61.

Railroad car 100 ton double weighbridges with dial scale, trade mark VTsd-100, of the Krasnodar Sovnarkhoz. State Register No. 1506-61.

Portable instrument for testing welded joints in rods and various mounting devices (casings and nets), trade mark PA-7 of the Krasnodar Sovnarkhoz. State Register No. 1507-61.

Rack-mounted ammeters and voltmeters, trade mark D150, of the Leningrad Sovnarkhoz. State Register No. 1508-61.

Waveguide measuring line, trade mark IVLU-140, of the State Committee for Radioelectronics of the USSR Council of Ministers. State Register No. 1509-61.

High-speed water meters with propellers in dimensions of 50, 80, 100, 150, 200, 250, and 300 mm, trade mark VV, of the Moscow City Sovnarkhoz. State Register No. 382-61, combined with previously registered water meters type VV under State Register No. 382.

Micrometer hole gauges, trade marks NM 150-1250, NM 75-600 and NM-50-75, of the Chelyabinsk Sovnarkhoz State Register No. 784-61, approved in place of previously registered micrometer hole gauges type 784 under State Register No. 784.

Telescopes for radiation pyrometers RAPIR with a range of 1200 to 2500°C, with lenses made of brand K-8 glass, trade mark TERA-50, of the Kaluga Sovnarkhoz, State Register No. 1352-61, combined with previously registered (under State Register No. 1352-60) telescopes for radiation pyrometers RAPIR, with trade mark TERA-50 and different measurement limits.

Mine interferometers, trade mark ShI-5, of the Novosibirsk Sovnarkhoz. State Register No. 1377-61, combined with mine interferometers, trade mark ShI-3, previously registered under State Register No. 1377-60.

IV. MEASURES AND MEASURING INSTRUMENTS EXCLUDED FROM THE STATE REGISTER

Traction gauges and thrust gauges with an elastic diaphragm. State Register No. 746.

Audio oscillators ZG-10. State Register No. 926. From July 1, 1962.

Audio oscillators ZG-12. State Register No. 1341-60. From July 1, 1962.

Soviet Journals Available in Cover-to-Cover Translation

ABBREVIATION	RUSSIAN TITLE		TITLE OF TRANSLATION	PUBLISHER	TRANSLATION BEGAN Vol.	Issue	Year
AÉ	Atomnaya énergiya		Soviet Journal of Atomic Energy	Consultants Bureau	1	1	1956
Akust. zh.	Akusticheskii zhurnal		Soviet Physics – Acoustics	American Institute of Physics	1	1	1955
	Antibiotiki		Antibiotics	Consultants Bureau	4	1	1959
Astr(on). zh(urn).	Astronomicheskii zhurnal		Soviet Astronomy–AJ	American Institute of Physics	34	1	1957
Avto(mat). svarka	Avtomaticheskaya svarka		Automatic Welding	British Welding Research Association (London)		1	1959
	Avtomatika i Telemekhanika		Automation and Remote Control	Instrument Society of America	27	1	1956
	Biofizika		Biophysics	National Institutes of Health*		1	1957
	Biokhimiya		Biochemistry	Consultants Bureau	21	1	1956
Byull. éksp(erim). biol. i med.	Byulleten' éksperimental'noi biologii i meditsiny		Bulletin of Experimental Biology and Medicine	Consultants Bureau	41	1	1959
DAN (SSSR) / Dokl(ady) AN SSSR	Doklady Akademii Nauk SSSR		The translation of this journal is published in sections, as follows:				
			Doklady Biochemistry Section	American Institute of Biological Sciences	106	1	1956
		Life Sciences	Doklady Biological Sciences Sections (Includes: Anatomy, biophysics, cytology, ecology, embryology, endocrinology, evolutionary morphology, genetics, histology, hydrobiology microbiology, morphology, parasitology, physiology, zoology sections)	American Institute of Biological Sciences	112	1	1957
		Life Sciences	Doklady Botanical Sciences Sections (Includes: Botany, phytopathology, plant anatomy, plant ecology, plant embryology, plant physiology, plant morphology sections)	American Institute of Biological Sciences	112	1	1957
		Chemical Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Chemical Technology	Consultants Bureau	106	1	1956
		Chemical Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Chemistry	Consultants Bureau	106	1	1956
		Chemical Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Physical Chemistry	Consultants Bureau	112	1	1957
		Earth Sciences	Doklady Earth Sciences Sections (Includes: Geochemistry, geology, geophysics, hydrogeology, mineralogy, paleontology, petrography, permafrost sections)	American Geological Institute	124	1	1959
		Earth Sciences	Proceedings of the Academy of Sciences of the USSR, Section: Geochemistry	Consultants Bureau	106-123	1-6	1957-1958
		Earth Sciences	Proceedings of the Academy of Sciences of the USSR, Sections: Geology	Consultants Bureau	106-123	1-6	1957-1958
		Mathematics	Doklady Soviet Mathematics	The American Mathematics Society	131	1	1961
		Physics	Soviet Physics–Doklady (Includes: Aerodynamics, astronomy, crystallography, cybernetics and control theory, electrical engineering, energetics, fluid mechanics, heat engineering, hydraulics, mathematical physics, mechanics, physics, technical physics, theory of elasticity sections)	American Institute of Physics	106	1	1956
		Physics	Proceedings of the Academy of Sciences of the USSR, Applied Physics Sections (does not include mathematical physics or physics sections)	Consultants Bureau	106-117	1	1956-1957
Derevoobrabat. prom-st'.	Derevoobrabatyvayushchaya promyshlennost'		Wood Processing Industry	Timber Development Association (London)		9	1959
	Élecktrosvyaz		Telecommunications	Massachusetts Institute of Technology*		1	1957
Éntom(ol). oboz(renie)	Éntomologicheskoe obozrenie		Entomological Review	American Institute of Biological Sciences	38	1	1959
Farmakol. (i) toksikol(ogiya)	Farmakologiya i toksikologiya		Pharmacology and Toxicology	Consultants Bureau	20	1	1957
FMM	Fizika metallov i metallovedenie		Physics of Metals and Metallography	Acta Metallurgica*	5	1	1957
Fiziol. zhurn. SSSR (im. Sechenova)	Fiziologicheskii zhurnal im. I. M. Sechenova		Sechenov Physiological Journal USSR	National Institutes of Health*		1	1957
Fiziol(ogiya) rast.	Fiziologiya rastenii		Plant Physiology	American Institute of Biological Sciences	4	1	1957
	Geokhimiya		Geochemistry	The Geochemical Society		1	1958
FTT	Fizika tverdogo tela		Soviet Physics–Solid State	American Institute of Physics	1	1	1959
Izmerit. tekh(nika)	Izmeritel'naya tekhnika		Measurement Techniques	Instrument Society of America		1	1959
Izv. AN SSSR, O(td). Kh(im). N(auk)	Izvestiya Akademii Nauk SSSR: Otdelenie khimicheskikh nauk		Bulletin of the Academy of Sciences of the USSR: Division of Chemical Sciences	Consultants Bureau		1	1952

continued

Izv. AN SSSR, O(td). T(ekhn). N(auk):. Met(all). i top.	(see Met. i top.)	Bulletin of the Academy of Sciences of the USSR: Physical Series	Columbia Technical Translations		1 1954
Izv. AN SSSR Ser. fiz(ich).	Izvestiya Akademii Nauk SSSR: Seriya fizicheskaya	Bulletin (Izvestiya) of the Academy of Sciences USSR: Geophysics Series	American Geophysical Union		1 1954
Izv. AN SSSR Ser. geofiz.	Izvestiya Akademii Nauk SSSR: Seriya geofizicheskaya	Izvestiya of the Academy of Sciences of the USSR: Geologic Series	American Geological Institute		1 1958
Izv. AN SSSR Ser. geol.	Izvestiya Akademii Nauk SSSR: Seriya geologicheskaya	Soviet Rubber Technology	Research Association of British Rubber Manufacturers	18	1 1959
Kauch. i rez.	Kauchuk i rezina	Kinetics and Catalysis	Consultants Bureau	1	3 1960
	Kinetika i kataliz	Coke and Chemistry USSR	Coal Tar Research Association (Leeds, England)		1 1958
	Koks i khimiya		Consultants Bureau	14	1 1952
Kolloidn. zh(urn).	Kolloidnyi zhurnal	Colloid Journal	American Institute of Physics	2	1 1957
	Kristallografiya	Soviet Physics – Crystallography			1 1958
Metalov. i term. obrabot. metal.	Metallovedenie i termicheskaya obrabotka metallov	Metal Science and Heat Treatment of Metals	Acta Metallurgica	6	1 1957
	Metallurg	Metallurgist	Acta Metallurgica		1 1960
Met. i top.	Metallurgiya i topliva	Russian Metallurgy and Fuels	Eagle Technical Publications		1 1957
Mikrobiol.	Mikrobiologiya	Microbiology	American Institute of Biological Sciences	26	6 1959
OS	Optika i spektroskopiya	Optics and Spectroscopy	American Institute of Physics		1 1958
	Pochvovedenie	Soviet Soil Science	American Institute of Biological Sciences		
	Priborostroenie	Instrument Construction	British Scientific Instrument Research Association		1 1959
Pribory i tekhn. éks(perimenta)	Pribory i tekhnika éksperimenta	Instruments and Experimental Techniques	Instrument Society of America		1 1957
Prikl. matem. i mekh.	Prikladnaya matematika i mekhanika	Applied Mathematics and Mechanics	American Society of Mechanical Engineers		1 1958
PTÉ	(see Pribory i tekhn. éks.)		National Research Council of Canada		
	Problemy Severa	Problems of the North	Massachusetts Institute of Technology*	12	1 1957
Radiotekh.	Radiotekhnika	Radio Engineering	Massachusetts Institute of Technology*	2	1 1957
Radiotekh. i élektronika	Radiotekhnika i élektronika	Radio Engineering and Electronics	Production Engineering Research Assoc.		1 1959
	Stanki i instrument	Machines and Tooling	Iron and Steel Institute		1 1959
Stek. i keram.	Stal'	Stal (In English)	Consultants Bureau	13	1 1956
Svaroch. proiz-vo	Steklo i keramika	Glass and Ceramics	British Welding Research Association		4 1959
Teor. veroyat. i prim.	Svarochnoe proizvodstvo	Welding Production	Society for Industrial and Applied Mathematics		1 1956
	Teoriya veroyatnostei i ee primenenie	Theory of Probability and Its Applications			1 1960
Tsvet. Metally	Tsvetnye metally	Nonferrous Metals	Primary Sources		1 1958
UFN	Uspekhi fizicheskikh Nauk	Soviet Physics – Uspekhi (partial translation)	American Institute of Physics	66	1 1960
UKh	Uspekhi khimii	Russian Chemical Reviews	The Chemical Society (London)		
UMN	Uspekhi matematicheskikh nauk	Russian Mathematical Surveys	London Mathematical Society	15	1 1960
Usp. fiz. nauk	(see UFN)				
Usp. khim(ii)	(see UKh)				
Usp. matem. nauk	(see UMN)				
Usp. sovr. biol.	Uspekhi sovremennoi biologii	Russian Review of Biology	Oliver and Boyd		48 1959
Vest. mashinostroeniya	Vestnik mashinostroeniya	Russian Engineering Journal	Production Engineering Research Assoc.		4 1959
Vop. gem. i per. krovi	Voprosy gematologii i perelivaniya krovi	Problems of Hematology and Blood Transfusion	National Institutes of Health*		1 1957
Vop. onk.	Voprosy onkologii	Problems of Oncology	National Institutes of Health*		1 1957
Vop. virusol.	Voprosy virusologii	Problems of Virology	National Institutes of Health*		1 1957
Zav(odsk). lab(oratoriya)	Zavodskaya laboratoriya	Industrial Laboratory	Instrument Society of America	25	1 1959
ZhAKh Zh. anal(it). khimii	Zhurnal analiticheskoi khimii	Journal of Analytical Chemistry USSR	Consultants Bureau	7	1 1952
ZhETF Zh. éksperim. i teor. fiz.	Zhurnal éksperimental'noi i teoreticheskoi fiziki	Soviet Physics–JETP	American Institute of Physics	28	1 1955
ZhFKh Zh. fiz. khimii	Zhurnal fizicheskoi khimii	Russian Journal of Physical Chemistry	The Chemical Society (London)		7 1959
ZhMÉi Zh(urn). mikrobiol. épidemiol. i immunobiol.	Zhurnal mikrobiologii, épidemiologii i immunobiologii	Journal of Microbiology, Epidemiology and Immunobiology	National Institutes of Health*		1 1957
ZhNKh Zh(urn). neorgan(ich). khim(ii)	Zhurnal neorganicheskoi khimii	The Russian Journal of Inorganic Chemistry	The Chemical Society (London)		1 1959
ZhOKh Zh(urn). obshch(ei) khimii	Zhurnal obshchei khimii	Journal of General Chemistry USSR	Consultants Bureau	19	1 1949
ZhPKh Zh(urn). prikl. khimii	Zhurnal prikladnoi khimii	Journal of Applied Chemistry USSR	Consultants Bureau	23	1 1950
ZhSKh Zh(urn). strukt. khimii	Zhurnal strukturnoi khimii	Journal of Structural Chemistry	Consultants Bureau	1	1 1960
ZhTF Zh(urn). tekhn. fiz.	Zhurnal teknicheskoi fiziki	Soviet Physics–Technical Physics	American Institute of Physics	26	1 1956
Zh(urn). vyssh. nervn. deyat. (im. Pavlova)	Zhurnal vysshei nervnoi deyatel'nosti (im. I. P. Pavlova)	Pavlov Journal of Higher Nervous Activity	National Institutes of Health*		1 1958

*Sponsoring organization. Translation through 1960 issues is a publication of Pergamon Press.

SIGNIFICANCE OF ABBREVIATIONS MOST FREQUENTLY ENCOUNTERED IN SOVIET TECHNICAL PERIODICALS

AN SSSR	*Academy of Sciences, USSR*
FIAN	*Physics Institute, Academy of Sciences USSR*
GITI	*State Scientific and Technical Press*
GITTL	*State Press for Technical and Theoretical Literature*
GOI	*State Optical Institute*
GONTI	*State United Scientific and Technical Press*
Gosénergoizdat	*State Power Press*
Gosfizkhimizdat	*State Physical Chemistry Press*
Goskhimizdat	*State Chemistry Press*
GOST	*All-Union State Standard*
Gostekhizdat	*State Technical Press*
GTTI	*State Technical and Theoretical Press*
IAT	*Institute of Automation and Remote Control*
IF KhI	*Institute of Physical Chemistry Research*
IFP	*Institute of Physical Problems*
IL	*Foreign Literature Press*
IPF	*Institute of Applied Physics*
IPM	*Institute of Applied Mathematics*
IREA	*Institute of Chemical Reagents*
ISN (Izd. Sov. Nauk)	*Soviet Science Press*
IYap	*Institute of Nuclear Studies*
Izd	*Press (publishing house)*
LÉTI	*Leningrad Electrotechnical Institute*
LFTI	*Leningrad Institute of Physics and Technology*
LIM	*Leningrad Institute of Metals*
LITMiO	*Leningrad Institute of Precision Instruments and Optics*
Mashgiz	*State Scientific-Technical Press for Machine Construction Literature*
MGU	*Moscow State University*
Metallurgizdat	*Metallurgy Press*
MOPI	*Moscow Regional Pedagogical Institute*
NIAFIZ	*Scientific Research Association for Physics*
NIFI	*Scientific Research Institute of Physics*
NIIMM	*Scientific Research Institute of Mathematics and Mechanics*
NIKFI	*Scientific Institute of Motion Picture Photography*
NKTM	*People's Commissariat of the Heavy Machinery Industry*
Obrongiz	*State Press of the Defense Industry*
OIYaI	*Joint Institute of Nuclear Studies*
ONTI	*United Scientific and Technical Press*
OTI	*Division of Technical Information*
OTN	*Division of Technical Science*
RIAN	*Radium Institute, Academy of Sciences of the USSR*
SPB	*All-Union Special Planning Office*
Stroiizdat	*Construction Press*
URALFTI	*Ural Institute of Physics and Technology*
TsNIITMASh	*Central Scientific-Research Institute of Technology and Machinery*
VNIIM	*All-Union Scientific Research Institute of Metrology*

NOTE: Abbreviations not on this list and not explained in the translation have been transliterated, no further information about their significance being available to us — *Publisher.*

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